BORON AVAILABILITY AND RESPONSE OF BLACKGRAM TO BORON IN CALCAREOUS SOILS

BY

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B.Sc. (Ag.)

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(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)

CHAIRPERSON: Dr. P.R.K PRASAD

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2017

DECLARATION

I, V. HARISH, hereby declare that the thesis entitled **“Boron availability and response of blackgram to boron in calcareous soils”** submitted to the **Acharya N. G. Ranga Agricultural University** for the degree of **Master of Science in Agriculture** in the major field of **Soil Science and Agricultural Chemistry** is the result of original research work done by me. I also declare that no material contained in the thesis has been published earlier in any manner.

Place: Bapatla **(V. HARISH)**

Date: **I.D. No. BAM-14-22**

CERTIFICATE

Mr. V. HARISH has satisfactorily prosecuted the course of research and that the thesis entitled **"Boron availability and response of blackgram to boron in calcareous soils"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him for a degree of any university.

Date**:**

Plac**e :** Bapatla

(Dr. P.R.K. PRASAD)
Associate Dean
Agricultural College, Bapatla - 522101.

CERTIFICATE

This is to certify that the thesis entitled **"Boron availability and response of blackgram to boron in calcareous soils"** submitted in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** in the major field of **Soil Science and Agricultural Chemistry** of the Acharya N. G. Ranga Agricultural University, Lam, Guntur is a record of the *bonafide* original research work carried out by **Mr. V. HARISH** under my guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma or has been published. The published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by the author of the thesis.

Thesis approved by the student advisory committee

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Place: Bapatla

Date: ***(V.HARISH)***

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LIST OF SYMBOLS AND ABBREVIATIONS

% : Per cent
@ : At the rate of
< : Less than
> : Greater than
≥ : Greater than or equal to
& : And
^{0}C : Degree Celsius
AP : Andhra Pradesh
B : Boron
Ca : Calcium
$CaCl_2$: Calcium chloride
$CaCO_3$: Calcium carbonate
µM : Micromolar
CD @ 5% : Critical difference at 5 per cent probability level
CEC : Cation exchange capacity
cm : Centimetre
cmol (p^+) kg^{-1} : Centimole of unit positive charge per kilogram
CO_2 : Carbon dioxide
CRD : Completely randomised design
CV : Coefficient of variation
Cu : Copper
DAS : Days after sowing
dS m^{-1} : Deci Siemen per metre
DTPA : Diethylene triamine penta acetic acid
EC : Electrical conductivity
EDTA : Ethylene diamine tetra acetic acid
Eh : Redox potential
ESP : Exchangeble Sodium Percentase

et al. : And others
etc., : Etcetera
Fe : Iron
Fig. : Figure
g : Gram
g pot^{-1} : Gram per pot
g^{-1} : Per gram
μg pot^{-1} : Microgram per pot
ha^{-1} : Per hectare
H_2SO_4 : Sulphuric acid
HCl : Hydrochloric acid
HNO_3 : Nitric acid
$HClO_4$: Per chloric acid
i.e. : That is
K : Potassium
K_2O : Potassium oxide
kg : Kilogram
kg ha^{-1} : kilogram per hectare
L^{-1} : Per litre
kg^{-1} : Per kilogram
km : Kilometre
M : Molar
m.eq : Milli equivalent
mg pot^{-1} : Milli gram per pot
mmol : Milli moles
Mg m^{-3} : Mega gram per cubic metre

ml : Millilitre

mm : Millimetre

Mn : Manganese

N : Nitrogen

Na : Sodium

NH_4^+-N : Ammonical nitrogen

NO_3^--N : Nitrate nitrogen

NaOH : Sodium hydroxide

NH_4OAC : Ammonium acetate

NI : Nutrient index

nm : Nano meter

No. : Number

NS : Non - significant

OC : Organic carbon

ppm : Parts per million

P : Phosphorus

PBS : Per cent base saturation

P_2O_5 : Phosphorus pentoxide

pH : Potential of hydrogen ion concentration

r : Correlation coefficient

R^2 : Coefficient of multiple determination

RDF : Recommended dose of fertilizer

S : Sulphur

SEm : Standard error of mean

viz. : Namely

Zn : Zinc

ABSTRACT

Name of the Author : **V. HARISH**

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The present investigation entitled “Boron availability and response of blackgram to boron in calcareous soils” was conducted for assessing the boron availability status of calcareous soils as it is one of the important factors controlling yield of the crops.

Representative surface soil samples (50) were collected from different locations of Sattenapalli mandal in Guntur district by following random sampling technique. The major soil textural classes identified in the soils of the mandal were sandy clay and clay. Out of which, clay was the dominant texture. The soils were slight to strongly calcareous in nature. The investigation revealed that content of the clay was significantly and positively correlated with $CaCO_3$ content (r= 0.29*) and exchangeable Ca^{2+} (r=0.56**). Whereas, organic carbon content showed a negative correlation (r= -0.37*) with $CaCO_3$ content. The soils of the study area were neutral to moderately alkaline in reaction. Negative correlation was observed between pH and soil available B (r= -0.32*). Bulk density and water holding capacity of soils varied from 1.23 - 1.55 Mg m^{-3} and 45.23 - 58.89 per cent, respectively in the mandal. The cation exchange capacity was in between 32.61 and 52.17 cmol (p+) kg^{-1} with high base saturation varying from 86.66 to 98.73 per cent. The exchangeable bases on the exchange complex followed a trend of $Ca^{2+} > Mg^{2+} > Na^{2+} > K^{+}$.

The soil nutrient index in respect of organic carbon, nitrogen and phosphorus was low and was high with potassium. Calcareousness of soils adversely affected the nutrient availability in the sampled locations. $CaCO_3$

content was negatively correlated with available N and available P_2O_5 (r = -0.34*). Whereas, available K content of soils showed a positive correlation with $CaCO_3$ content (r = 0.30*). Soils in the mandal were deficient in boron (64%) and sufficiently rich in iron (90%), manganese and copper. Calcareousness of soils was highly negative in correlation with soil available boron (r = -0.593**). Micronutrients *viz.* Fe, Zn and Cu also showed a negative trend with $CaCO_3$ content.

Soil samples of different calcareous levels up to 15 cm depth were collected in bulk from five selected locations of the mandal based upon preliminary investigation carried out. A pot culture experiment was conducted in the green house at Department of Soil Science and Agricultural Chemistry, Agricultural College, Bapatla during 2015-16 to find out the response of blackgram to different levels of boron in calcareous soils. The treatment combinations were taken based on different levels of boron *viz.* 0.0, 0.25, 0.50 and 0.75 mg kg^{-1} at different levels of $CaCO_3$ (1.02, 5.25, 10.37, 16.20, 17.75 %) and replicated thrice in completely randomized block design.

Irrespective of the soil calcareousness, increasing doses of boron enhanced the biomass production, seed yield, nutrient content and uptake by blackgram. Whereas, decrease in biomass, seed yield and nutrient uptake was noticed with increasing levels of $CaCO_3$. Application of B @ 0.25 mg kg^{-1} (B_1) in soils containing 1.08% $CaCO_3$ was found sufficient to produce optimum yield of blackgram although maximum yield obtained with application of B @ 0.50 mg kg^{-1} soil (B_2) was on par with B_1 level. For all other soils having more than 1.08% $CaCO_3$ content, the yields increased with increase in B doses.

Chapter I

INTRODUCTION

Pulses are the primary source of vegetable proteins for the growing population of our country and an integral part of many diets across the globe and they have great potential to improve human health, conserve our soils, protect the environment and contribute to global food security. The United Nations declared2016 as “International Year of Pulses” (IYP) to heighten public awareness of the nutritional benefits of pulses as part of sustainable food production. India has the distinction of being the world’s largest (25% of global production) producer of grain legumes (pulses). Even then production is not adequate to ensure even the minimum per capita requirement of 80 g recommended by World Health Organization and Food and Agricultural Organization. In fact it dropped from 60 g in 1951-56 to 50 g in 2012-2014. The area under pulses has been fluctuating around 24-26 million hectares producing 17-19 million tonnes with productivity of 781 kg per hectare (Mohanty and Satyasai, 2015).Therefore it is imperative to increase the pulse production to bridge the gap between human consumption and the requirement.

Among the pulse crops, blackgram [*Vigna mungo* (*L.*)] is one of the highly priced pulses of India. Blackgram seeds are highly nutritious with protein (25-26%), carbohydrate (60%), fats (1.5%) and significant amount of minerals, amino acids and vitamins. In India, blackgram is grown in an area of 2.07 million hectares with a production of 0.94 million tonnes (Rajiv and Prakash, 2012).

Boron is known to enhance vegetative growth, nodulation and nodule activity and also to play an important role in retention of flowers and pods in pulses (Mandal *et al.*, 2012). Boron is essential for normal development of reproductive tissues and its deficiency results in low grain set or poor seed quality (Dell *et al.*, 2002). Its deficiency during the early growth considerably decreased leaf photosynthetic rate and carbohydrate transport from leaves to fruits and depressed plant growth and dry matter accumulation, resulting in increased fruit abscission (Heitholt, 1994).In blackgram (*Vigna mungo* L.), no symptoms of B deficiency may be visible, yet grain yield may be reduced by up to 50 percent (Sakal *et al*., 1988).

Due to intensive cropping and use of high yielding varieties had caused depletion of soil fertility especially of micronutrients. Imbalanced NPK fertilization also resulted in deficiency of boron in soils. Boron (B) is one of the most common deficiencies in soils of India. Its deficiency is found in nearly 30% of the soils of the country, which are highly calcareous, leached or sandy (Mondal *et al*., 1991; Sakal *et al*., 1996; Maji *et al*., 2013).

Boron is mostly deficient in calcareous soils. Moderately high soil pH ($\geq$ 7.5) and low organic matter (OM) content (< 0.5%) of calcareous soils are major causes of low B availability to plants. Calcareous soils contain sufficient amount of calcium carbonate. Calcium carbonate is likely to decrease Bavailability. Besides, calcium carbonate acts as a sink for boron in the soil, where it adsorbs a great portion of the soluble boron on the surface of their particles (Goldberg and Forster, 1991;Shaaban*et al*., 2004, 2006).

Kaisher *et al*. (2010) observed that soil applied boron at the rate of 5 kg B ha^{-1} had significant effect on yield and yield attributing characters of greengram. Shrila *et al*., (2013) reported that soil applied boron at the rate of 10 kg borax per hectare was found better than 5 kg borax ha^{-1} for chickpea in calcareous soils of Pantnagar.

Padhusan and Kumar (2014) revealed that among the four levels of soil applied boron viz. 0.5, 0.75, 1.0, 1.5 mg B kg^{-1} and two levels of foliar applied boron viz. 0.1 and 0.2 per cent borax solution, soil applied boron 0.5 mg B kg^{-1} and foliar application of 0.1% performed well and showed significant effect on yield and yield attributes of mungbean.

Keeping in view the factors influencing the boron availability and its significance in crop nutrition in calcareous soils, the present investigation is proposed with the following objectives.

OBJECTIVES

1. To assess the available boron status of calcareous soils.

2. To correlate soil properties with available boron content.

3. To assess the response of blackgram to boron application in calcareous soils.

Chapter II

REVIEW OF LITERATURE

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2.1. IMPORTANCE OF BORON FOR CROPS

Boron (B) is a unique non-metal micronutrient required for normal growth and development of plants. In 1923, it was first time reported by Warington (1923), that B was essential for cell structure of plants, where it controlled porosity and tensile strength (Ryden *et al.*, 2003).As a part of the cell membranes, B was important for sugar transport, cell wall synthesis, lignification, cell wall structure integrity, carbohydrate metabolism, ribose nucleic acid (RNA) metabolism, respiration, indole acetic acid (IAA) metabolism, phenol metabolism (Parr and Loughman, 1983; Welch, 1995; Ahmad *et al*., 2003).

Many reports from agricultural practice had well established that adequate B supply was imperative for obtaining high yields and good qualitybut boron deficiency was a widespread problem for field crop production where large losses of yield occur annually both quantitatively and qualitatively (Shorrocks, 1997; Oosterhuis and Zhao., 2003).

2.1.1. Functions of Boron in Crops

Pollen grains of most species were naturally low in boron, but in the styles, stigma, and ovaries, boron concentrations were generally high (Ginsburg, 1961). He reported that a continuous and ample supply of boron was required for pollen tube growth, and speculated that the boron was complexing with cellular materials during the tube elongation process. Along this line, Johri and Vasil (1995) demonstrated that boron was more critical for pollen tube elongation than for pollen germination.

The key role of boron in plants included membrane integrity, cell wall formation, pollen tube growth and utilization of carbohydrates (Marschner, 1995).

Vitosh *et al.* (1997) reported that boron was important in cell division, pod and seed formation and it had a positive role on protein synthesis.

This was the fact that > 90 % of the total B was contained in cell walls (Martin and Thellier, 1993). Boron was concerned along with (Ca) in cell wall structure. Boron was able to outline complexes with cell wall components such as pectins (Brown and Hu, 1996), polyhydroxyl polymers and polyols (Matoh *et al.*, 1999). That was why; responsibility of boron had been implicated in the synthesis and stability of cell wall by forming esters with cis-diol group present in the cell wall. This provided rigidity, strength and shape to the cell (Fleischer *et al*., 1998).

Boron ranks third among micronutrients after zinc, for its concentration in seed and stem as well as its total amount. A large part of plant B waslocalised in the cellwallpecticfraction, where it formed a cross-linking structure with rhamnogalacturonan-II (RG-II) units (Matoh *et al*, 1999).

Boron hasan important role in the functioning of enzymes and other proteins of the plasma membrane, transport processes across the membrane, and membrane integrity (Goldbach *et al*., 2001; Brown and Dordas, 2002).

The function of B in the formation and stabilisation of the primary cell wall structure was confirmed by O'Neill *et al* (2001). Boron was involved in cell multiplication and nitrogen metabolism (Sinha and Chatterjee, 2003).

Boron was involved in the activation of enzymes necessary for starch synthesis and hence for cellulose production (El-Hamdaoui *et al*., 2003; Hansch and Mendel, 2009). It played an active role in the transport of sugars from the site of synthesis to meristem regions of stem and roots (Bolanos *et al*., 2006).

Application of B activated the absorption of other nutrients, photosynthetic efficiency, phosphorus uptake, hormone synthesis and fat metabolism (Tewari *et al*., 2009).

The requirement of B was more for reproductive development than for vegetative growth (Pandey and Gupta, 2013).

Boron was neither a constituent of enzymes nor it activated any of the enzymes. Most important function of B was to form stable complexes with organic compounds. It was responsible for the cell wall formation and stabilization, lignification and xylem differentiation. It imparts drought tolerance to the crops. It played a role in pollen germination and pollen tube growth. It facilitated ion uptake by way of increasing the activities of plasma membrane bound H^+-ATPase. It facilitated transport of K in guard cells as well as stomatal opening (Behera *et al*., 2014).

Boron has an important role in the colonization of Mycorrhiza at the root surface and there by influenced P and K uptake. It also regulated K/Ca ratio in plants. Research had shown that boron was important in nitrogen fixation and nodulation in legumes. Boron played an important role in plant diseases control. It synthesized lignin as a pathogen barrier and restricted fungal hyphae from movement through the cell walls. Boron application was reported to decrease rust in wheat and control postharvest gray mold in grapes (caused by *Botrytis cinerea*) by strongly inhibiting spore germination, germ tube elongation, and spread of mycelia **(**Tarlok, 2014).

2.1.2. Deficiency of Boron in Crops

Bonilla *et al.* (1997) reported that boron deficiency caused structural aberrations in cell walls of root nodules due to lack of the covalently bound hydroxyproline or proline rich proteins, which contributed to an O_2 barrier, preventing inactivation of nitrogenase and associated decrease in N_2 fixation. Rate of water adsorption and carbohydrate translocation was also restricted due to boron deficiency.

The unavailability of boron during grain setting period resulted in poor anther and pollen development (Cheng and Rerkasem, 1993) and the grain thus formed were often without starch (Dell and Huang, 1997).

Deficiency of boron in wheat resulted in male sterility in boron deficient alkaline calcareous soils of Pakistan (Rashid *et al.*, 1997; Shorrocks, 1997).

B deficiency resulted in white and rolled tips of emerging leaves, reduced plant height; severe deficiency could cause the death of growing point although new tillers continue to be produced. Boron deficiency at the panicle formation stage might fail to produce panicles in rice (Dobermann and Fairhurst, 2000).

Boron deficiency during the early growth of cotton increased leaf chlorophyll content, decreased leaf stomatal conductance and net photosynthetic rate and reduced non-structural carbohydrate export from the leaf to the fruit, resulting in increased fruit abscission and a change in dry matter partitioning after squaring (Oosterhuis and Zhao, 2003).

A normal ear fails to flower and development of the inflorescence and setting of spikelets was restricted in wheat due to boron deficiency (Rerkasem and Jamjod, 2004).

Typical symptoms of boron deficiency on shoots were crickled and stunted leaves, upward cupping of leaves, chlorosis of upper leaves, decreased leaf expansion, aborted growing tips and fast growing auxillarry shoots, yellowing and red veins on the terminal shoots, dead terminal shoots and die back, death of small areas in the trees bark and tip of the shoots followed by progressive death of the inner bark and cambium (Brown and Hu, 1996; Jiao *et al.*, 2005).

The B deficiency symptoms in the roots include reduced growth with brown discoloration of the root tips, symptoms could be seen on the fruits included mall flatten or misshapen fruits, drought spot, internal cork cracking and russet in apple, premature ripening, increased fruit drop and low seed count (Blevins and Lukaszewski, 1998; Pilbem and Morely, 2007).

Rate of water adsorption and carbohydrate translocation restricted in crops due to boron deficiency (Tewari *et al.*, 2009).

Ahmad *et al.* (2012) revealed that deficiency of boron caused prominent reduction of growth, nodulation, yield percentage, vigour and viability in legume and cereal crops.

In annual crops, the symptoms of boron deficiency varied from one species to another. Blackgram deficient in boron did not show any visible symptoms, but the yield might fall by as much as 50 per cent. In peanut or soybean, boron deficiency often resulted in an empty space within the seed, known as "hollow heart". A common result of boron deficiency in all crops as an interruption in flowering and fruiting. Boron deficiency symptoms become conspicuous on the terminal buds or the youngest leaves. Internodes become shorter and give a bushy or a rosette appearance. B deficiency of different crops were known as heart rot of sugar beet and marigold, browning or hollow stem of cauliflower, top sickness of tobacco and internal cork of apple **(** Behera *et al.*, 2014).

2.2. EXTENT OF BORON DEFICIENCY IN CALCAREOUS SOILS

Sobrinho and Freire (1980) recognized that several B responsive soils in the Brazil were recognized as latosols (Ferralsols), podzolic soil, Luvisols and Acrisols where water soluble B levels were normally < 0.50 mg kg^{-1}. Anspoks and Liepins, (1987) demonstrated the extremely low B contents in Podzols of Poland. Likewise, few researchers reported that the majority of southern Finland were prone to hold < 0.50 mg B L^{-1}.

The soil maps of China demonstrated vast areas of soils keeping really low hot water soluble B levels (<0.25 mg kg^{-1}). In north of China, soils developed from calcareous and loess alluvium originated from Yellow river, therefore B deficiency was commonly intrinsic. Conversely, the arid region soils of western China were B loaded and typically categorized as Lithic Yermosols and Lithic Kastanozems. Whereas in India, investigations on soil B status and crop responses to B application illustrated that outstanding B was deficit observed in various states. The available B in these calcareous soils ranges from 0.06-8.00 ppm with a mean value of 0.77 ppm. On the basis of 0.53 ppm critical limit of available B, 51% soils of Muzaffarpur, 32% of Samastipur, 43% of Siwanand 49% of Gopalganj districts were found deficient in B with an overall deficiency of 48% (Zheng *et al.,* 1989; Chang, 1993).

Rahmatullah *et al.* (1999) conducted field and greenhouse experiments to assess the importance of B distribution in calcareous soils as it influenced its bioavailability and discharge for plant utilization.Out of nine soils employed in this investigation, 8 soils were medium textured and exceptionally low in OM content. Except the Shahdara series (tested at 0.30 mg kg^{1}), hot water soluble B passed its critical boundary of 0.50 mg kg^{-1} in all soils. Total B content ranged from 31-41 mg kg^{-1} while non-specifically adsorbed B (extracted by $CaCl_2$), specifically adsorbed B (extracted by mannitol), B occluded in Mn hydroxides (extracted by HCl-NH_2OH) and B occluded in non-crystalline Al and Fe oxy hydroxides (extracted by NH_2-oxalate) were 1.20 %, 17.40, 55.90 % and 10.50 to 23.80 % of total soil B, respectively.

Boron deficiency had been realized as the second most important micronutrient constraint in crops after that of zinc (Zn) on global scale. In soils, concentration of total B was reported to be in the range of 20 to 200 mg kg^{-1} (Mengel and Kirkby, 1987), and its available concentrations also vary greatly from soil to soil. Boron deficiency was one of the major constraints to crop production (Sillanpaa, 1982), and had been reported in more than 80 countries and for 132 crops over the past 60 years (Shorrocks, 1997). Boron deficiency had been commonly reported in soils which were highly leached and/or developed from calcareous, alluvial and loessial deposits (Takkar *et al.*, 1989; Razzaqand Rafiq, 1996; Borkakati and Takkar, 2000).

Katyal and Randhawa (2004) reported that total average B content in Indian soils differed from 3.80-630 mg kg^{-1} and this total B content had no any significance to plant availability. They analyzed 36825 soil samples, and reported that 33 % were deficient in available B. According to them, many crops responded to B application in different agroecological provinces of India (Sarkar, 2006).

Sakal and Singh (1995) identified Bihar, Orissa, Meghalaya, Karnataka, West Bengal, Assam and Gujarat as predominantly B deficient areas in India. They further reported that in Maharashtra most of the soils rarely pointed out B deficiency as these soils were created from the basalts of the deccan trap. Likewise, other Indian researchers also reported B deficiency in soils of India and responses of different crops to B application (Sarkar, 2006; Sarkar *et al.*, 2006).

2.3. FACTORS AFFECTING BORON AVAILABILITY IN SOILS

Plants obtained all the essential nutrients from soil medium through their roots, consequently all the soil properties were directly associated with the availability of influential nutrients particularly B. The availability of B was influenced by dynamic soil properties including organic matter, texture, soil pH, EC and calcareousness of soil as well as quality of irrigation water and cultural practices like fertilization (Shorrocks, 1997; Borax, 1998; Mengel and Kirkby, 2001).

2.3.1. Soil Texture

Ellis and Knezek (1972) reported that vermiculite adsorbed more B than any other minerals. Similarly, Elrashidi and O‟Connor (1982) reported significant positive correlation between B and clay content. Boron followed the following order for adsorption on clay minerals: kaolinite < montmorillonite <illite. Fine textured soils retained more B compared with coarse textured soils (Keren and Mezuman, 1981).

Boron adsorption in fine-textured soils was higher compared with the coarse- and medium-textured soils at the same equilibrium concentration. The level of native B was also closely related to the clay content of the soil (Elrashidi and O'Connor, 1982; Raza *et al.,* 2002). Coarse-textured soils often contained less available B than fine-textured soils (Raza *et al*., 2002; Malhi *et al*., 2003).

Boron deficiencies are often observed in plants grown in sandy soils. Soil adsorbed B found to be soil texture dependent and increased with increasing clay content (Shaaban *et al.,* 2004 and 2006).

Soil textures markedly affected the availability of B to plant. Among soil separates, clayis a major sink for B adsorption on its exchange sites (Mezuman and Keren, 1981; Elrashidi and O‟Connor, 1982). Niaz *et al*. (2002) concluded that B concentrations of coarse- and medium-textured soils and plants grown in such soils were lower than their respective critical levels, because these soils were well drained and had good leaching. The mechanism of B adsorption on these surfaces was considered to be ligand exchange with reactive surface hydroxyl groups leading to strong specific adsorption (Goldberg and Chunming, 2007).

2.3.2. Water Holding Capacity

Low water may cause depressed mineralization of B from organic matter by micro- organisms. Low plant transpiration may also induce B deficiency (Fleming, 1980).

Gupta (1968) revealed that adsorption of B was reliant on equivalences and symmetries when soil water content ranged from 50-100 % of FC (field capacity). Conversely, the findings of Mezuman and Keren (1981) showed that B adsorption enhanced with declining moisture content. Further, few scientists also worked on wetting and drying cycles in relation to B adsorption and they illustrated that it enlarged with boost in wetting and drying rotations. The impacts of drying turned distinct with intensifying B additions (Keren and Gast, 1981).

Low soil water status may depress B uptake, even though its level was high in soil. Drying of soil depressed water uptake therefore decreased the supply of B reaching the plant roots through mass flow (Evans and Sparks, 1983).

2.3.3. Soil Reaction

Soil pH is one of the most important factors affecting the availability of B in soils. Boron uptake by plants growing in soil, with the same water soluble B concentration, was noticed to be higher where pH of the soil solution was lower (Wear and Patterson, 1962). Soil pH has specific impact on B availability more in terms of sorption reactions than by formation of fewer soluble compounds. Mortvedt *et al.* (1999) reported that at pH range of 5.5 to 7.50, the availability of B was highest. Boron was sorbed to Fe and Al oxides in soils and its availability was lowest at pH range of 6.0 to 9.0.

Rodriguez *et al.* (2001) revealed that pH had certain impacts on B removal in de-salination and reverse-osmosis reactions or processes. Several reports showed that pH directly controlled the B availability to higher plants and B adsorption on primary soil particles (sand, silt or clay) enhanced with pH (particularly at pH 5 to 9). Necessarily this means that greater the pH, the more firmly the B is adsorbed to soil. Consequently, with each unit rise in pH, B turned into gradually more unavailable to the plants (Albion, 2003).

In a recent study, few researchers revealed that calcite was typically utilized to raise pH of soil however it maximized soil B fixation (Chen *et al.*, 2009). They further investigated that adsorption of B straight forwardly amplified with elevation in pH and soil pH had certain impacts on adsorption and desorption hysteresis of soils.

Soil pH affected plant growth and nutrient availability, therefore B at high pH was less available to plant specially cotton and wheat (Rashid, 2005; Communar and Keren, 2006). Some studies showed that pyrophyllitic soils and different ions played a significant role in B adsorption in relation to pH (Communar and Keren, 2006).

Boron bioavailability had become less at higher solution pH. Consequently, application of lime to acid soils, in excessive amounts, could sometimes render plants deficient in B. There was a close association with the pH of the soil solution and the level of soluble B in soils (Rashid *et al.*, 1994; Niaz *et al.,* 2002, 2007).

The adsorption of B by soils increased as a function of soil solution pH in the range from 3 to 9 (Lehtoand Malkonen, 1994)and it decreased when the pH was increased further in the range 10 to 11.5 (Goldberg and Glaubig, 1986b). In several studies, highest levels of B adsorption by soil depicted close correlation with the pH of the soil solution (Shafiq *et al.,* 2008).

2.3.4. Organic Matter

Yermiyaho *et al.* (1988) conducted an experiment on B sorption on composted organic matter and their results showed that at pH 8.0, the extent of sorbed B enhanced by almost 57 %. They also determined the sorption isotherms of B on organic matter at three pH levels of soil (7.0, 7.90 and 8.90).

Marzadori *et al.* (1991) reported that the amount of B adsorbed by three soils differing in chemical and physical properties was more after the removal of organic matter. Thus, it was suggested that a portion of the oxides of Fe and Al, and other possible adsorption sites coated or occluded by OM, only became active after removal of OM. Adsorption of B on a soil humic acid increased with an increasing soil pH up to a maximum 9, thereafter B adsorption decreased with increasing pH > 9.0 (Gu and Lowe, 1990). Goldberg (1997) proposed ligand exchange as a possible mechanism for B adsorption by OM.

Boron adsorption in mineral soil increased with increasing SOM (Yermiyaho *et al.*, 1995).

Yermiyahu *et al.* (2001) studied the functions of soil OM content on B uptake by bell pepper along with soil solution B concentration. They revealed that OM significantly affected B uptake by plants. Moreover they reported that uptake of B by plant was relatively controlled by soil solution B levels than total soil B content. The OM was primed from the solid proportion of alienated straw-containing livestock dung. He categorized it as mature compost (COM). On the commencement of the trial, B concentration in the soil solution diminished with improving rates of COM and ultimately growing levels of COM guided to smaller amount of B in the leaf tissues. This decline in B concentration was more at elevated levels of B application. Similarly, the consequences of COM level on plant B concentration were too enormous at highest B application levels. Adjusted soil solution B concentration was positively correlated with the leaf B concentration.

Organic matter is an important factor affecting the availability of B. Soil B was positively correlated with organic carbon content (Zhu and Liu, 1999). Organic matter was a major storehouse of available B for crop use. Many researchers conducted experiments on organic matter (OM) in relation to available B fraction and they concluded that organic matters straightforwardly bestowed an imperative responsibility in controlling the soil solution B concentration and there was a significant role of OM in de-sorption or adsorption of B in soils (Marzadori *et al.*, 1991). Furthermore, SOM had a significant outcome on dropping B removal by plants (Yermiyahu *et al.*, 2001).

Soil organic matter adsorbed more B than mineral soil constituents on a weight basis (Gu and Lowe, 1990). This was considered as the leading source of reserve B because it complexed with B to remove it from the soil solution when the levels were high after B fertilization (Borax, 1998). It then re-supplied the soil solution to sustain ample levels when B was removed by crops or leaching occurred. Boron associated with humic colloids was the principal B pool for plant growth in most of the agricultural soils (Jones, 2003).

Soil organic matter (SOM) greatly affected the avaialbity of B (Goldberg, 1997). Earlier, Parks and White (1952) reported that humus was important for B retention in soils. Availability of B from SOM depended on its decomposition. Thus, destruction of SOM with hydrogen peroxide (H_2O_2) resulted in release of B in plant available form and also a reduction in its fixation by clays (Gu and Lowe, 1990). The strongest evidence that OM affected the availability of soil B was derived from studies that showed a positive correlation between levels of SOM and the amount of hot water-soluble B (Niaz *et al.*, 2002 and 2007; Shafiq *et al.*, 2008).

Communar and Keren (2008) studied different impacts of dissolved organic matter (DOM) and treated sewage effluents on B adsorption in soils. They revealed that concentrations of micro and macro elements with organic matter amplified in treated sewage waste-matter via their complexation at pH of 7.70. The influences of humus on adsorption of B were more than that of DOM. Moreover, DOM formed various complexes with free soil solution-B. Consequently, soil B concentration significantly reduced as the total DOM concentration increased.

Organic matter (OM) was the storehouse for most nutrients in soil and known to improve soil health and availability of plant nutrients. Many researchers had suggested that the level of soil organic matter (SOM) influenced the nutrient bioavailability (Sarwar and Mubeen, 2009).

2.3.5. Calcium Carbonate Content

The calcareous soils were alkaline in nature. Hence, the deficiencies of micronutrients were common problem. B deficiency was common in most of the calcareous soils. Patel and Golakiya (1986) reported that the hot water soluble boron also decreased significantly with increasing of $CaCO_3$. B adsorption on the fine particles of $CaCO_3$, the excess Ca interferes in the B nutrition of crops. The occurrence of free Ca ions restricted B availability in soils. The plants required more of B when Ca supply was high. Adsorption of B was very much pH dependent and maximum adsorption occurred at pH 8-9. The co-precipitation of B with $CaCO_3$ could occur in calcareous soils which affected the B distribution in the liquid phase of the soil (Keren and Bingham, 1985; Gupta *et al.*, 1985).

There was an interaction between B availability and the presence of Ca ions. High levels of Ca at high pH reduced the uptake of B. This might explain the fact that high B levels in calcareous soils, considered as toxic in other conditions, did not produce B toxicity in crops (Lucas and Knezek, 1972). Retention of B on calcium carbonate occurred via an adsorption mechanism (Scott *et al.*, 1975). The mechanism could be exchange with carbonate groups. The magnitudes of the B adsorption maxima for soil samples treated to remove calcium carbonate were statistically significantly lower than those for untreated soil samples indicating that calcium carbonate acted as an important sink for B adsorption in calcareous soils (Goldberg and Forster, 1991).

$CaCO_3$ acted as B adsorbing medium in calcareous soils because it raised the soil solution pH. B adsorption was greater on soils having higher $CaCO_3$. This B adsorption was due to the bonding of B with $CaCO_3$ which resulted into precipitation of Ca-borate or substitution of Carbon by B in $CaCO_3$ or simple surface adsorption of B on $CaCO_3$ (Keren and Ben-Hur, 2003).

Application of lime increased B fixation in soils because it raised the soil solution pH (Lehto and Malkonen, 1994). In addition to its effect on soil pH, calcium carbonate also acted as an important B adsorbing surface in calcareous soils. Boron adsorption was greater on soils having higher calcium carbonate content. Boron adsorption on reference calcites increased with increasing solution pH from pH 6 to 9, exhibited a maximum at pH 9.5, and decreased with increasing solution pH from pH 10 to 11 (Goldberg and Forster, 1991; Communar *et al.,* 2004).

According to some studies, B sorption was increased due to elevated levels of calcite in soil and liming diminished the water-soluble B content of soils (Goldberg and Forster, 1991; Lehto and Malkonen, 1994). In Pakistan soils, some amount of B was adsorbed on clays or gradually complexed within organic matter (Rashid, 2005) and to some extent it was precipitated with $CaCO_3$ and was quite unavailable for plant growth. Fertilizer efficiency was incredibly low in Pakistan because majority of soils were alkaline in reaction (high pH) and calcareous in nature (Rashid, 2005; Gop, 2006).

Acid soluble B was highly significantly correlated with calcium carbonate content of soils (Elseewi and Elmalky, 1979). Magnitude of B adsorption on clay minerals was affected by the exchangeable cation (Evans, 1987). Calcium clays adsorbed more B than sodium and potassium clays. An explanation for this result was that calcium 2:1 clays occur as tactoids consisting of several clay particles while the sodium forms exist in solution as single particles. In tactoids, the diffused double layer and negative electric field from the planar surfaces was less extensive, making the edge sites of calcium clays more accessible to adsorbing borate anions than those of sodium clays. An alternative explanation for increased B adsorption in the presence of calcium was the formation and adsorption of the calcium borate ion pair. Indian literature also showed that some soil factors directly influenced the B availability and these also were responsible for B adsorption (Keren and Gast, 1981; Mattigod *et al.*, 1985; Sarkar, 2006).

Shaaban *et al.* (2006) reported that addition of calcium carbonate increased the pH value of the soil. Thus calcium carbonate was likely to decrease the B-availability.

2.3.6. Interaction with Other Nutrients

A significant relationship has been found between K and B fertilizers regarding their assimilation or uptake by crop plants as well as crop produce (Hill and Morrill, 1975). At heavy applications of K and other intensive production practices B was needed to prevent reduction in corn yield (Woodruff *et al.*, 1987).

Many contending ions such as silicate, phosphate, oxalate and sulfate reduced the extent of adsorption of B on certain oxides. Some studies revealed that in the case of phosphate and sulfate, B adsorption was significant and inconsequential, respectively. The results of Metwally *et al.* (1974) showed that the potential of competing ions to leach adsorbed B from some oxides enhanced in the order of: phosphate >sulfate >arsenate >chloride and considerable silicate adsorption created hardly an insignificant decline in adsorption of B by Al-oxide revealing that a little B sorption spots exhibit B tendency (Goldberg and Glaubig, 1986a).

Yang and Gu (2004) studied the effect of B on Al toxicity on seedlings of soybean cultivars. The results showed that high B was found to ameliorate Al toxicity by significantly increasing the growth characters including root length under 2 mM Al stress, and epicotyl length and fresh weight under 5 mM Al stress of the cultivars studied. Similar kind of study conducted by Hossain and Hossain (2004) which confirmed the relationship of B with Al.

Graham *et al.* (1987) found that B uptake by barley (*Hordeum vulgare L.*) was lower when Zn was applied compared to in its absence. Further, they also showed that rate of B accumulation in plants was increased even at low levels of Zn and high levels of P. Therefore, Zn fertilization reduced B accumulation, and lessened the risk of toxicity in plants (Ahmed *et al.*, 2008).

The ratio between Ca and B in the plant was sometimes used to identify B deficiency. In a recent study, application of both Ca and B to different cultivars of maize significantly enhanced shoot dry matter production whereas, B concentration in the shoot of maize cultivars was antagonized with Ca application. A curvilinear relation was exhibited between Ca/B ratio in shoot and relative shoot dry matter in B deficient calcareous soils (Kanwal *et al*., 2008).

Some functions of B interrelated with those of nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca) in plants. Its interaction (synergistic or antagonistic) with most of the nutrients (N, P, K, Ca, Mg, Al, and Zn) might be sometimes influential in regulating B availability to plants in soil (US Borax, 2009).

2.4. EFFECT OF BORON FERTILIZATION ON BIOMASS PRODUCTION, NUTRIENT CONTENT AND UPTAKE BY CROPS GROWN IN CALCAREOUS SOILS

2.4.1. Growth Parameters

2.4.1.1. Plant height

Hemantaranjan *et al*. (2000) conducted a field experiment on the effect of foliar applied boron and soil applied iron and sulphur on growth and yield of soybean and found that foliar spray of 50 ppm boron significantly resulted in higher plant height.

Sarker *et al*. (2002) showed that application of sulphur and boron at different levels individually showed a significant effect on growth parameters and boron @ 4 kg ha^{-1} produced higher plant height and number of branches in soybean.

Rajni and Meitei (2004) conducted an experiment to find out the effect of boron and zinc on growth and yield of French bean. Results indicated the significant increase in plant height with the application of boron (1.0 ppm) after 20 and 40 days of sowing.

Reddy and Majumder (2004) revealed that the foliar application of 0.02% B + 40 ppm IAA increased the plant height (38.94 cm) in blackgram.

Rao *et al*. (2005) conducted a field experiment by application of 50 ppm mepiquat chloride, 1.25 ppm triacontanol, 0.2% borax and 1% potassium nitrate on chickpea and they found that foliar application of Borax @ 0.2% increased the plant height (39.0 cm) compared to control (33.1cm).

Higher values of plant height were recorded with N dose of 40 kg per feddan combined with 25 ppm boron in fababean (Mahmoud *et al*., 2006).

Significant increase in plant height was recorded in greengram with foliar application of boron @ 0.2 per cent along with DAP @ 2 per cent, NAA @ 40 ppm and Mo @ 0.05 per cent by Pradeep and Elamathi (2007).

Harmankaya *et al*. (2008) reported that average plant height of chickpea genotypes increased by 4% in B soil application and 9% in B foliar application over control in B deficient calcareous soils.

Bangar *et al*. (2010) conducted a field experiment on soyabean MAU, Parbhani during kharif season and stated that B @ 15 kg ha^{-1} increased the plant height (50.2cm) compared to control (39.8 cm).

Meena *et al.* (2011) conducted an experiment during kharif on soybean. They observed an increase in growth with the application of 1.0 kg B/ha as compared to control.

Ahmad *et al.* (2012) revealed that deficiency of boron cause prominent reduction of growth in legume and cereal crops.

Tahir *et al.* (2013) reported that the application of boron at 4 kg ha^{-1} significantly increased plant height (58.03 cm).

2.4.1.2. Dry matter production

Hemantaranjan *et al.* (2000) conducted a field experiment on the effect of foliar applied boron and soil applied iron and sulphur on growth and yield of soybean and found that foliar spray of 50 ppm boron significantly resulted in higher total dry matter.

From the results of a field experiment conducted during the rabi season of 1997-98 in Tirupati, Andhra Pradesh, India, Aruna *et al*. (2001) reported that the foliar application of 0.5 per cent boric acid along with 2% DAP, 0.5% $ZnSO_4$on groundnut resulted in the highest dry matter accumulation.

Shankhe *et al*. (2003) conducted a field experiment on groundnut (TAG-24) in Maharashtra during kharif season and concluded that foliar application of boron resulted in significant increase in dry matter over control.

Higher drymatter accumulation was recorded with N dose of 40 kg per feddan combined with 25 ppm boron in fababean (Mahmoud *et al*., 2006).

Significant increase dry weight of plants were recorded in greengram with foliar application of boron @ 0.2 per cent along with DAP @ 2 per cent, NAA @ 40 ppm and Mo @ 0.05 per cent by Pradeep and Elamathi (2007).

Srinivasan and Angayarkanni, (2008) reported that dry matter accumulation increased with the increase in B rate up to 15 kg/ha in groundnut.

Bangar*et al*. (2010) conducted afield experiment on soyabean at MAU, Parbhani during kharif season and stated that B @ 15 kg ha^{-1} increased the total dry matter (24.7 g/plant) compared to control (22.5 g/plant).

Niaz *et al*. (2011) reported that dry matter yield of irrigated cotton increased significantly with B application up to 2.0 kg ha^{-1}.

2.4.1.3. Nutrient content and uptake

Sakal *et al* (1988) reported that application of 4 kg boron in the form of borax to chickpea recorded maximum total uptake of boron (281.76 q ha^{-1}) in a field experiment with varying levels of B (0, 0.5, 1.0,1.5,2.0 2.5,3.0 and4.0 kg B ha^{-1}) and these studies revealed that B and K were synergistic in sandy loam soil having pH 8.6 and hot water soluble B of 0.34 ppm.

Praba and singaram (1995) reported that application of B as soil and foliar application significantly increased the uptake of macro and micro nutrients with 30 kg borax ha^{-1} treatment. The highest P uptake by shoot (0.115g pot^{-1}) was recorded in 0.3% boron as foliar application. K uptake recorded maximum in shoot (0.372g pot^{-1}) with boronated super phosphate with equivalent basis of P. Calcium uptake in shoot (0.941 g pot^{-1}) was maximum with 30 kg borax ha^{-1}. Highest Mg uptake in shoot (0.183g pot^{-1}) was recorded with 0.3% boron as foliar application. B uptake by shoot (8.77 µg pot^{-1}) was highest in 0.3% boron foliar application in a red calcareous soils with pH 8.5, CaCO3 3.7% and with low boron content (hot water soluble boron in soil 0.25 ppm) as a pot culture experiment with Hybrid Naveen and Co-3 varieties.

In an experiment on soybean it was shown that sulphur and boron applied individually, affected the nutrient uptake significantly. Plants receiving boron @ 1 kgha^{-1} produced seeds with higher protein and oil contents (Sarker *et al.*, 2002).

O Neill *et al.* (2004) reported that boron supply increased the uptake and reutilization of N, P, K, Na, Ca and other nutrients in mungbean.

Harmankaya *et al.* (2008) reported that the leaf B concentration of chickpea genotypes increased by 12% in B soil application and 37% in B foliar application over control in B deficient calcareous soils.

Waghdhare *et al.* (2008) concluded that foliar application of boron@280 mgkg^{-1} through solubor or borax twice at 15days interval starting from just prior to flowering is beneficial for increasing nutrient content and uptake of tomato on alkaline calcareous boron defecient soils.

Application of B might improve the utilization of applied N in cotton plants by increasing the translocation of N compounds into the bolls (US Borax, 2009).

Hossain *et al.* (2011) found that the total N, P, K, S, Zn, and B uptake by mustard was significantly influenced by B application. The highest uptake N, P, K, S, Zn, and B was observed with 1 kg B/ha, which was significantly higher over B control but statistically identical with subsequent higher B dose (2 kg B/ha).

Niaz *et al.* (2011) concluded that the application of boron fertilizer caused increase in the accumulation of N, P, K, Cu, Fe, Zn, and B in different parts of the cotton plant.

Shamsuddoha *et al.* (2011) conducted a field experiment on effect of sulfur and boron on nutrients in mungbean and soil health and reported that a statistically significant variation was recorded for N, P, K, S and B concentration and uptake in mungbean stover and grain due to the application of different levels of B.

Nandini *et al.* (2012) revealed that soil application of boron @ 1.5 kg ha^{-1} resulted in higher total uptake of boron in soybean.

Ganie *et al.* (2014) reported a marked increase in N, P K, S and B concentration and uptake in pods and stover at pod picking and seeds and stover at harvesting stages of the crop (French bean) with the application of boron. The contents and uptake of these nutrients increased significantly by increasing boron level up to 1.5 kg/ha, however, these results were at par to 1.0 kg/ha .

2.5. EFFECT OF BORON FERTILIZATION ON YIELD AND YIELD COMPONENTSOF CROPS GROWN IN CALCAREOUS SOILS

Patel and Golakiya (1986) conducted pot culture experiment to study the effect of boron on the yield of groundnut(cultivar G.G-1) in medium black calcareous soils having pH 7.4,$CaCO_3$ 3.5% and hot water soluble B 0.66 ppm . The results indicated that among different treatments (0.0, 0.25, 0.5, 1.0 and 2.0 ppm B), 2.0 ppm B foliar spray recorded the highest pod yield (67.3g pot^{-1}) compared to control (64.6 g pot^{-1}) with C.D 1.8 at 5% level.

Sakal *et al.* (1988) reported that application of boron at 2.0 and 2.5 kg B ha^{-1} to coarse textured highly calcareous soils having pH 8.6 and water soluble B as 0.34 ppm increased the grain yield of black gram (925 kg ha^{-1}) and chickpea(2.33 kg ha^{-1}).

Sarker *et al.* (2002) from their experiment on soybean reported that individual application of boron @ 1 kg ha^{-1} produced significant increase in yield components, biological yield, seed yield and harvest index.

Number of pods per plant, number of seeds per pod, seed yield per plant, straw and seed yield per feddan were significantly improved in fababean by applying nitrogen @ 40 kg nitrogen per faddan along with 50-100 ppm boron (Mahmoud *et al.,* 2006).

Harmankaya *et al.* (2008) reported that average yield of chickpea genotypes increased by 10% in B soil application and 20% in B foliar application over control in B deficient calcareous soils.

Waghdhare *et al.* (2008) concluded that foliar application of boron @280 mgkg^{-1} through solubor or borax twice at 15days interval starting from just prior to flowering is beneficial for increasing yield of tomato on alkaline calcareous boron deficient soils.

Tewari *et al.* (2009) stated that application of B activates the absorption of other nutrients.

Hossain *et al.* (2011) found that yield of mustard was significantly influenced by B application. The highest yield observed with 1 kg B/ha, which was significantly higher over B control but statistically identical with subsequent higher B dose (2 kg B/ha).Quddus *et al.* (2011) concluded that the combination of $Zn_{1.5}$ $B_{1.0}$ with blanket dose of N_{20} P_{25} $K_{35}S_{20}$ kg/ha was found suitable for maximizing the yield of mungbean in calcareous Low Ganges River Floodplain soil at Madaripur region of Bangladesh.

Ahmad *et al.* (2012) revealed that deficiency of boron cause prominent reduction of yield percentage, vigour and viability in legume and cereal crops. Nandini *et al.* (2012) reported that soil application of boron @ 1.5 kg ha^{-1} resulted in maximum yield in soybean. This might be due to the role of boron in cell differentiation and development, translocation of photosynthates and growth regulators from source to sink and its involvement in protein synthesis. Naveen and Stalin (2012) revealed that soil application of $ZnSO_4$ and Borax @ 50 kg and 10 kg ha$^{–1}$ respectively combined with recommended 100% NPK ha$^{–1}$ to the proceeding crop, significantly recorded the highest dry pod and haulm yield with increase being 52.16 and 50.7% over control for the successive residual blackgram.

Tahir *et al.*, (2013) revealed that the application of boron at 4 kg ha^{-1} significantly increased number of pods plant^{-1} (21.33), 1000-seed weight (35 g), protein content (20.53 %), number of nodules plant^{-1} (13.33), biological yield (7688 kg ha^{-1}) and seed yield (1200 kg ha^{-1}). Raza *et al.* (2014) conducted experiment on response of wheat (*Triticumaestivum. L*) to application of boron in calcareous soils of Pakistan. Results showed that effect of B was significant on grain yield, number of grains spike^{-1}and 1000 grain weight. The highest grain yield of wheat (6.5 ton ha^{-1}) was observed when 10 mg L^{-1} B was applied. Application of 20 mg L^{-1} B resulted in a significant decline in wheat grain yield (4.7 ton ha^{-1}). The detrimental effects of the highest B application on yield components were also observed. The decline in the quantity and quality of yields with increasing B might be due to the toxicity effect of higher concentration of foliar application.

Vaseghi *et al.* (2013) showed that soil application of boron @ 0.28 kg ha^{-1} significantly increased the pod number and grain yield in soybean.

Chapter III

MATERIAL AND METHODS

The details pertaining to the methodology adopted and the materials used in the present investigation entitled “Boron availability and response of Blackgram to Boron in Calcareous soils” are presented here.

3.1 LOCATION AND GENERAL DESCRIPTION OF THE STUDY AREA

The present study area, i.e Sattenapalli mandal of Guntur district is located in East coast of Andhra Pradesh, India (Figure 3.1). It is located 37 KM towards west from District head quarters Guntur. Globally it lies between 16^0 39’ Northern latitude and 80^0 14’ Eastern longitudes at an average elevation of seventy one metres above mean sea level and sixty four kilometres to the west of the Bay of Bengal. The study area consists of eighteen villages bounded by Medikonduru and Pedakurapadu mandals on East, Krosuru mandal on North, Rajupalem mandal on West and Muppalla and Phirangipuram mandals on south. The total geographical area of the district is 2188 ha. In the study area most of the people depend on agriculture for their livelihood.

3.2PARENT MATERIAL

Soils of Sattenapalli mandal was formed by the weathering of the lime stone (Pullaiah *et al.*, 2000).

3.3 RELIEF

The slope of the soils under study is less than 1 per cent with majority falling in plain topography followed by low lands.

3.4 SOURCES OF IRRIGATION

The Krishna River lies partly in the study area which is the major source of irrigation through Nagarjun sagar right canal and Guntur branch channel. The minor irrigation sources of the study area are tanks and bore wells.

3.5 CLIMATE

The climate of the area is subtropical, dry, sub humid with well expressed seasons. The mean annual temperature is 29^0C with mean annual precipitation of 905 mm. Most of the rain is experienced by both south-west monsoon and the retreating monsoon.

3.6 NATURAL VEGETATION AND LAND USE

The natural vegetation comprises a wide variety of dry deciduous tree species and shrubs inter spread with grasses. Most commonly occurring tree and grasses *spp* in the study area are *Acacia*, *Borassus*, *Tamarindus*, *Azadirachta*, *Pongamia, Cynodon, Cyperus, Lantana and Chloris barbata*etc.

The principal crops grown in the study area during the *kharif* season are paddy, cotton, chillies, turmeric, tobacco, maize, jowar, bajra, blackgram, greengram and redgram. The major cropping systems followed in areas where irrigation facilities available are cereal crops followed by cereals or pulses. Among the crops cultivated, paddy has emerged as the predominant crop followed by cotton and chillies. The other crops grown are maize, jowar, bajra, tobacco and vegetables.

3.7 COLLECTION AND PROCESSING OF SOIL SAMPLES

3.7.1. Collection of the Soil Samples

Fifty locations were selected at random which were calcareous in nature (tested with cold dilute HCl). All surface soil samples (0-15 cm depth) were collected from cultivated fields prior to sowing by following random sampling technique during the month of June (23-05-2015 to 13-6-2015) covering 11 villages in the Sattenapalli mandal of Guntur district (Table 3.1). The soils of the study area are calcareous, heterogeneous and were dileanated into homogeneous sampling area based on variation in colour, texture and crops grown. A ‘V’ shaped pit was made to a depth of 15 cm with spade and the samples were collected at random by following a zig zag movement from the entire homogeneous area. All samples representing one homogeneous area were pooled and mixed together and reduced to one kg size by following quartering method.

3.7.2. Processing of the Soil Samples

The samples thus collected were shade dried, powdered and ground with a wooden hammer and passed through a 2 mm sieve. Finally, the samples were transferred to air tight poly bags and were labelled with information like sample number, place, co-ordinates and depth of sampling.The bulk soil samples were collected from Nandigama, Kantepudi, Bhurugupadu, Bhatluru and Pakalapadu locations based on $CaCO_3$ content. The sites from where soil samples were collected are depicted in figure 3.2 and details are given in appendix.

The surface soil sample were analysed for texture, BD, WHC, pH, EC, $CaCO_3$, organic carbon, CEC, exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), PBS, available macronutrients(N, P, K,S)and available micronutrients (Zn, Mn, Fe, Cu and B).

3.8 SOIL ANALYSIS

3.8.1 Physical Properties

3.8.1.1 Soil texture

Mechanical analysis of soils for textural classification was done by Bouyoucos hydrometer method (Bouyoucos, 1962) after destroying organic matter using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexameta phosphate.

3.8.1.2Bulk density

Bulk density was determined by clod method as per procedure given by Black and Hartge (1986).

3.8.1.3 Water holding capacity

Water holding capacity was determined by Keen Raczkowski's method as described by Sankaram (1966).

3.8.2 Physico-chemical Properties

3.8.2.1 Soil reaction (pH)

Soil reaction was determined in 1:2.5 soil:water suspension using combined glass electrode DIGISUN electronics pH meter model: DI-707 (Jackson, 1973).

3.8.2.2 Electrical conductivity

The soluble salt content of soil samples was determined in supernatant liquid of 1:2 soil:water extract using electrical conductivity bridge CM - 180 (Jackson, 1973).

3.8.2.3 Cation exchange capacity

The cation exchange capacity measures the total quantity of negative charges per unit weight of soil and was determined by equilibrating the known weight of soil sample with sodium acetate solution (pH 8.2). The excess sodium acetate was removed by washing with absolute ethyl alcohol. Then the adsorbed sodium was replaced by equilibrating with neutral normal ammonium acetate solution and the concentration of sodium in the leachate was measured using flame photometer (Bower *et al.,* 1952) and the CEC was expressed as cmol (p^+) kg^{-1} soil.

3.8.2.4 Exchangeable cations

The exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) of the soils were extracted by centrifuge extraction procedure using neutral normal ammonium acetate as described by Bower *et al.* (1952). The sodium (Na^+) and potassium ions (K^+) in the extract were determined by aspirating directly into flame photometer, whereas calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions by Versenate method (Kanwar and Chopra, 1976).

3.8.2.5 Base saturation

It is defined as the extent to which the exchange complex of a soil is saturated with exchangeable basic cations(K, Na, Ca and Mg) and it is expressed as percentage of the total cation exchange capacity. The per cent base saturation of the soils was computed by the formula

$$PBS = \frac{\text{cmol}(p^+)\text{ of basic cations kg soil}^{-1}}{\text{Total CEC in cmol}(p^+)\text{ kg soil}^{-1}} \times 100$$

3.8.3 Chemical Properties

3.8.3.1 Organic carbon

Wet chromic acid digestion method was followed to determine the organic carbon content of the soils as given by Walkley and Black (1934).

3.8.3.2 Calcium carbonate

The calcium carbonate content of soil was estimated as per the procedure described by Puri, 1930.

3.8.3.3 Available nitrogen

Available nitrogen content in the soils was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956).

3.8.3.4 Available phosphorus

The available phosphorus of the soil samples was extracted by employing Olsen's (0.5 M $NaHCO_3$, pH- 8.5). The extracted phosphorus by Olsen's reagent was determined using ascorbic acid as a reducing agent and the intensity of blue colour was measured in a Genesys 10S VIS spectrophotometer with red filter at a wavelength of 660 nm, as described by Watanabe and Olsen (1965). The available phosphorus was expressed as kg P_2O_5 ha^{-1} by multiplying the P content with 2.29.

3.8.3.5 Available potassium

Available potassium of the soil samples was extracted by using neutral normal ammonium acetate (Muhr *et al.,* 1965). The potassium in the extracts was determined by using Systronics model 121 flame photometer and was expressed as kg K_2O $ha^{-1}$by multiplying the K content with 1.2.

3.8.3.6 Available sulphur

Available sulphur in soil was extracted with 0.15% $CaCl_2.2H_2O$ solution as described by Williams and Steinbergs (1959) and sulphur with extract was estimated by turbidimetric method (Cottoenie *et al.,* 1979).

3.8.3.7 Available micronutrients

20 grams of soil was shaken with 40 mL of DTPA extractant of pH 7.3 for 2 hours. The contents were filtered and in the filtrate available zinc, copper, iron and manganese were determined by using atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.8.3.8 Available boron

Available boron content of the soil was determined by a Azomethine-H method (Tandon, 1993).

3.9 PREPARATION OF SOIL TEST SUMMARIES

The analytical data of soils was summarized to evaluate the fertility status of the soils.

Ratings for soil samples

Soil samples were classified into low, medium and high categories as per the limits suggested by Ramamoorthy and Bajaj (1969) for organic carbon and available nitrogen. The ratings followed for available phosphorus and potassium as per Muhr *et al* (1965).The ratings followed for available sulphur as per Gupta *et al.*(2012), micronutrients as per Lindsay and Norvell (1978) and Boron as perGupta *et al.*(2012). Based on the $CaCO_3$ content, soils were categorised in to 5 classes as per limits given by Day (1983).The ratings for soil reaction (pH) and electrical conductivity (EC) were followed as communicated by Department of Agriculture, Andhra Pradesh (2007).

The ratings adopted for different parameters are given in table 3.1, 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7respectively.

Table 3.1. Rating chart for soil reaction

S.No.	Category	pH	Classes given by
1	Acidic	0 - 6.5	Department of Agriculture, A.P, 2007
2	Neutral	6.6 - 7.3	
3	Slightly alkaline	7.4 - 7.8	
4	Moderately alkaline	7.9 - 8.4	
5	Highly alkaline	> 8.4	

Table 3.2. Rating chart for electrical conductivity

S.No.	Category	Sandy soil	Loamy soil	Clay soil	Classes given by
1	Normal	0.1-1.0	0.2-1.5	0.1-2.0	Department of Agriculture, A.P, 2007
2	Critical for germination	1.0 - 3.0	1.6 - 3.0	2.0 - 6.0	
3	Injurious to most of the crops	> 3.0	> 4.5	> 6.0	

Table 3.3. Rating chart for organic carbon

S.No.	Category	OC (%)	Classes given by
1	Low	< 0.5	Ramamoorthy and Bajaj (1969)
2	Medium	0.5-0.75	
3	High	>0.75	

Table 3.4.Rating chart for calcium carbonate

S.No.	CaCO3 (%)	Calcareous class	Proposed by
1	<5	Slightly calcareous	Day(1983)
2	5-15	Moderately calcareous	
3	15-25	Strongly calcareous	
4	25-40	Very strongly calcareous	
5	>40	Extremely calcareous	

Table 3.5. Rating chart for macronutrients

S.No.	Macronutrient	Low	Medium	High	Proposed by
1	Available N (kg ha^{-1})	<280	280-560	>560	Ramamoorthy and Bajaj (1969)
2	Available P_2O_5 (kg ha^{-1})	<22.4	22.4-56	>56	
3	Available K_2O (kg ha^{-1})	<168	168-336	>336	Muhr*et al.* (1965)
4	Available S (ppm)	<10	10-20	>20	Gupta *et al.* (2012)

Table 3.6. Rating chart for micronutrients

S.No.	Micronutrient(ppm)	Deficient	Sufficient	Limits proposed by
1	Zinc	<0.8	≥0.8	Lindsay and Norvell (1978)
2	Iron	<4.5	≥4.5	
3	Manganese	<2	≥2	
4	Copper	<0.2	≥0.2	
5	Boron	<0.5	≥0.5	Gupta *et al.* (2012)

3.10 COMPUTATION AND CLASSIFICATION OF NUTRIENT INDEX

Nutrient index values for organic carbon, available nitrogen, phosphorusand potassium in soils were worked out as per the following formula given byParker *et al.* (1951).

$$\text{Nutrient index} = \frac{\begin{pmatrix} No.of samples \\ under low \\ category \times 1 \end{pmatrix} + \begin{pmatrix} No.of samples \\ under medium \\ category \times 2 \end{pmatrix} + \begin{pmatrix} No.of samples \\ under high \\ category \times 3 \end{pmatrix}}{Total number of samples}$$

Table 3.7 Nutrient indices for organic carbon, available N, P_2O_5 and K_2O

S.No.	Nutrient index	Category	Classes given by
1.	< 1.67	Low	
2.	1.67-2.33	Medium	Ramamoorthy and Bajaj (1969).
3.	> 2.33	High	

3.11 POT CULTURE EXPERIMENT

A pot culture experiment was conducted in the green house of Department of Soil Science and Agricultural Chemistry, Agricultural College, Bapatla during 2015 to find out the response of blackgram with different levels of boron application with calcareous soils collected from the study area. The experiment was laid out in a completely randomized design with two factors (Figure 3.3). The first factor was the soils (5) containing different levels $CaCO_3$(1.08, 5.25, 10.37, 16.20, 17.75) and the second factor was the levels of boron consisting of four levels 0.00, 0.25, 0.50 and 0.75 mg boron $kg^{-1}$of soil. Altogether there were twenty treatments and each treatment was replicated thrice. The detailed methodology followed for the pot culture experiment is given below

Five (calcareous) samples were selected out of 50 calcareous soil samples based on $CaCO_3$content. Soil samples of different calcareous levels up to 15 cm depth were collected in bulk from five locationsof the study area. Three kilograms of processed soil was transferred into earthern pots of equal size. Five blackgram seeds were sown in each pot. After establishing 3 seedlings were retained till harvesting. Boron was applied in the form of H_3BO_3 @ 0.00, 0.25, 0.50 and 0.75 mg kg^{-1} soil at the time of sowing. The crop was grown upto harvest stage.

Calcareous soil (Factor 1)	**Levels of Boron (Factor 2)**
S_1 : 1.08% $CaCO_3$	B_0 : 0.00 mg kg^{-1}
S_2 : 5.25% $CaCO_3$	B_1 : 0.25 mg kg^{-1}
S_3 :10.37% $CaCO_3$	B_2 : 0.50 mg kg^{-1}
S_4 :16.20% $CaCO_3$	B_3 : 0.75 mg kg^{-1}
S_5 :17.75%$CaCO_3$	

3.12 ESTIMATION OF DRYMATTERAND YIELD

The samples were air dried in a hot air oven at 65^{0}C. The dry matter yield was recorded on oven dry weight basis. The oven dried plant samples were powdered in a stainless steel grinder and stored in butter paper covers for further chemical analysis. The seed was collected and seed yield was also recorded.

3.13 PLANT ANALYSIS

3.13.1 Preparation of Plant Sample for Estimation of Nutrients

The harvested plant samples were washed first with tap water followed by 0.1 N HCl solution, distilled water and finally rinsed with double distilled water.The distilled was collected using quartz distillation flask and used for analysis. The samples were made free of sticking water drops by sandwiching them between sheets of clean blotting paper.

3.13.2 Nitrogen

The nitrogen content in blackgram plant samples was estimated by micro Kjeldahl distillation method (Piper, 1966).

3.13.3 Preparation of acid extract by wet digestion

One gram of powdered plant sample was taken in 150 mL Erlenmeyer flask and digested with diacid mixture (HNO_3 and $HClO_4$ in 9:4 ratio). The sample digest was filtered through Whatman No. 42 filter paper by washing the residue with double glass distilled water and made volume up to 100 mL and the clear extract was used for the determination of P, K, S, Fe, Zn, Cu and Mn.

3.13.3.1 Phosphorus

Phosphorus in the diacid extract of plant samples was estimated by Vanadomolybdo phosphoric yellow colour method using spectrophotometer at 420 nm wave length as described by Jackson (1973).

3.13.3.2 Potassium

Potassium in the diacid extract of plant samples was determined using flame photometer as per the method described by Jackson (1973).

3.13.3.3 Sulphur

Sulphur in the diacid mixture was determined by turbidometric method involving stabilizing agent (Vogel, 1973).

3.13.3.4 Micronutrients

Iron, manganese, copper and zinc in the diacid extract were determined using atomic absorption spectrophotometer as per the specifications mentioned by Lindsay and Norvell (1978).

3.13.4 Dry ashing of plant samples

One gram of dried, ground plant sample was placed in a silica crucible and the crucibles were placed in amuffle furnace and ignited at 550^0 C for 5hr. After cooling, the ash was dissolved in 5mL of 20% HCl and filtered through acid washed filter paper into a 100 mL volumetric flask. The solution was made up with double distilled water and mixed thoroughly.

3.13.4.1 Boron

Boron content in plant extract was determined by curcumin method as described by Tandon (1993).

* For B analysis both in soil samples and plant samples the distilled water is collected using quartz distillation set.

3.13.5 Nutrient Uptake

The uptake of nutrients at harvest was worked out by using the following formulae. Macronutrients uptake was expressed as mg pot^{-1} and micronutrient uptake was expressed in µg pot^{-1}.

Macronutrientuptake (mg pot^{-1}) =

$$\frac{\text{Nutrient concentration (\%)} \times \text{dry matter yield (g /pot)}}{100} \times 1000$$

Micronutrientuptake (µg pot^{-1}) =

$$\text{Nutrient concentration (ppm)} \times \text{dry matter yield (g pot}^{-1}\text{)}$$

3.14 STATISTICAL ANALYSIS

A simple correlation was worked out to study the relationship among the various soil properties with boron in soil by adopting procedure advocated by Panse and Sukhatme (1978). The data obtained from pot culture study was statistically analysed by using two factorial completely randomized design as outlined by Snedecor and Cochran (1967).

Chapter IV

RESULTS AND DISCUSSION

The results pertaining to studies on boron availability and response of blackgram to boron in calcareous soils of Sattenapalli mandal and green house studies are presented and discussed in this chapter.

4.1 Evaluation of properties of calcareous soils of Sattenapalli mandal Guntur district

4.2 Pot culture experiment

4.1 EVALUATION OF PROPERTIES OF CALCAREOUS SOILS OF SATTENAPALLI MANDAL,GUNTUR DISTRICT

4.1.1 Physical, Physico-chemical and Chemical Properties of the calcareous soils of Sattenapalli mandal

4.1.1.1 Physical properties of calcareous soils of Sattenapalli mandal

Texture

The data on particle size distribution and textural classification of the calcareous soils of the study area are presented in table 4.1. The per cent sand, silt and clay contents of the soils ranged from 33.5 to 51.50, 8.50 to 15.00 and 38.10 to 56.10 with mean values of 40.17, 11.88 and47.99respectively. Based on the per cent distribution of sand, silt and clay, the soils of the study area were classified into two textural groups’ *viz.*, sandy clay and clay.

Critical analysis of the data revealed that 84 per cent of the samples were under clay textureand 14 per cent was under sand clay texture. As per the USDA classification system, clay, sandy clay and silty clay textures were grouped as clay soils. On the whole, clay texture was the textural class in the study area. Similar particle size distribution was observed in Pamidimukkala mandal of Krishna district (Chandrasekhar, 2005).

Because of basic parent material and calcareous nature of these soils produced higher amount of clay. This was evidenced by a significant positive correlation (table 4.9) (r=0.298*) between calcium carbonate and clay content and also a positive regression (figure 4.1) (R^2=0.082) between calcium carbonate and clay. Singh and Prasad, (2000) observedsimilar particle size distributionin calcareous black soils formed in three agro-ecoregions of India.

Similar particle size distribution and textural classes were reported by Anita *et al.* (2001) in black soils of Gurjala mandal of Guntur district, Andhra Pradesh.

Bulk density

The data pertaining to the range and meanbulk density values of the calcareous soil samples are presented in table 4.2.

The bulk densityof soils varied from 1.23 to 1.55 $Mgm^{-3}$with a mean of 1.42 Mgm^{-3}. The highest (1.48 Mg m^{-3}) mean bulk density was observed in Abburu, while the lowest mean (1.34 Mg m^{-3})was in Nandigama village. It was observed that the bulk density was influenced by $CaCO_3$content of soils.

Leifeld *et al.* (2005) and Sakin (2012) obtained negative relationship between organic matter and bulk density of soils and showed significant correlation between them. Curtis and Post (2005) stated a reverse correlation between organic matter and bulk density. Morisada *et al.* (2004) determined the strongest correlation between bulk densities and organic matter among the data attained from the analytical results. Similar results were obtained with strong negative correlation (r = - 0.402**) (table 4.9)between organic matter and bulk density of soil samples and a regression coefficient (R^2) of 0.205 as depicted in figure 4.2. Thus the studies indicated that as the organic matter increased, the bulk density of soil decreased.

Water holding capacity

The data pertaining to the range and meanwater holding capacity values of the calcareous soil samples are presented in table 4.2.

The water holding capacityof soils varied from 45.23 to 58.89 with a mean of 51.16%. The highest (54.45%) mean in water holding capacity was observed in Nandigama while the lowest (47.18%) was in Abburu village. It was observed that the water holding capacity was dependent on clay content of soils.

A significant and positive (r=0.286*)(table 4.9) correlation and a positive regression coefficient (R^2=0.082) (figure 4.3) was observed between water holding capacity and clay content of the soils. This showed that water holding capacity of soil increased with increase in clay content of the soil. Organic carbon content of the soil also had positive correlation with water holding capacity of the soil. Similar results were reported by Bhaskar (2005).

4.1.1.2 Physico-chemical and Chemical Properties of the calcareous soils of Sattenapalli mandal

Soil reaction(pH)

The data pertaining to the range and mean pH values of the soil samples are presented in table 4.3 and depicted in the figure 4.5.

The overall soil pH values of all the villages ranged from 7.21 to 8.52 with a mean of 8.10 indicated that the soils were neutral to moderately alkaline in reaction. About 4 per cent of the samples were neutral(6.5-7.3) and found in soils of Bhatluru village while 6 per cent of the samples were slightly alkaline (7.4-7.8) and were found in Pedamakkena, Bhatluru and Kattamuru villages.

About 80 per cent of samples were moderately alkaline (7.8-8.4) in reaction and found in Nandigama, Pedamakkena, Gudipudi, kantepudi, Bhrugubanda, Bhatluru, Abburu, Pakalapadu, Kattamuru, Gandluru and Komerapudi villages. While 10 per cent of the samples were highly alkaline (>8.4) and were found in Bhatluru, Bhrugubanda and Pakalapadu villages of Sattenapalli mandal of Guntur district.

On the whole 96.0 per cent of the soils were alkaline (> 7.4). The higher pH in soils might be due to the presence of calcium carbonate and high base saturation with dominance of exchangeable basic cations. Similar pH values were earlier reported by Zekri *et al.* (2010) in the calcareous soils of Florida where it ranged from 7.6 to 8.5.

The neutral to highly alkaline pH of these soils might be due to presence of free calcium carbonate content and also probably reaction of applied fertilizer material with soil colloids, which resulted in the retention of basic cations on the exchangeable complex of the soils. This was evidenced by strong positive correlation between pH and calcium carbonate content (0.360**) of the soils (table 4.9) and a regression coefficient (R^2) of 0.190 as depicted in the figure 4.4. Similar opinion was earlier reported by Madhuvani *et al.* (2000) and Nayak *et al.* (2002).

Electrical conductivity

The data pertaining to the maximum, minimum and mean electrical conductivity values of soils of each villageare presented in table 4.3.

The electrical conductivity of soils varied from 0.04 to3.12 dSm^{-1} with a mean of 0.91dSm^{-1}. The highest (1.36dSm^{-1}) mean in electrical conductivity was observed in soils of Pakalapadu, while the lowest (0.66dSm^{-1}) mean value was in soils of Bhatluru village. Critical analysis of the data showed that all the samples studied were non-saline in nature.

The results indicated that there was no remarkable accumulation of soluble salts in the soils, which might be due to sufficient leaching and flushing of soluble salts into lower layers due to agronomic practices and irrigation of crops frequently. Similar EC values were earlier reported by Parihar *et al.* (2013) in calcareous soils of eastern Uttar Pradesh.

The results were in accordance with the findings of Vijayasankar babu *et al.* (2006), who stated that the EC in Vertisols of Anantapur district ranged from 0.12 to 0.49 dSm^{-1} and Revathi *et al.* (2005) in tomato growing soils of Madanapalle division of Chittoor district in Andhra Pradesh.

Organic carbon

The soil organic carbon content in calcareous soils of different villages of the Sattenapalli mandal ranged from 0.15 to 0.75 with a mean of 0.43 per cent (Table 4.2). The mean nutrient index value (table 4.8) of soil samples indicated that the soils were lowin organic carbon contentas depicted in figure 4.8.

The data further revealed that 72 per cent of soils were low and remaining 28 per cent were medium in organic carbon status. Similar status of organic carbon content was reported earlier in alluvial calcareous soils of Konya province by Srinivas *et al.* (2011).

The existence of low to medium organic carbon content of the soils was mainly due to less application of organic manures coupled with poor agro management practices such as tilling of soil, mono-cropping and burning of crop residues after harvest. Further, prevalence of alkaline soil reaction, calcareousness and semiarid conditions accelerated the degradation of added organic matter at a faster rate thereby leaving less organic carbon in the soils. This was evidenced bystrong negative correlation and regression (figure 4.6) (R^2=0.081) between organic carbon and calcium carbonate (r=-0.372**)(table 4.9). Soil pH (r=-0.025) also showed a negative correlation with organic carbon. Similar opinion was expressed by Leelavathi *et al.* (2009).

Calcium carbonate

The details pertaining to the range and mean contents of calcium carbonate of each village are presented in table 4.3and figure 4.9, respectively.

The calcium carbonate content of the soils varied from 1.08 to 17.75 per cent with a mean value of 5.56 per cent. The lowest (1.08 %) value of calcium carbonate was found in soils of Kantepudi village, while the highest (17.75 %) value was observed in soils of Bhrugubanda village.

Out of 50 soil samples, 60 and 32 per cent were slightly and moderately calcareous, while only 6 per cent of the samples were strongly calcareous in nature as per limits proposed by Day (1983). Similar calcium carbonate content ranging from 3 to 18 with a mean of 7.38 per cent was recorded by Chalwade *et al*. (2006) in swell shrink soils of five taluks of Latur district of Maharastra. Calcareous nature of the soils might be due to prevalence of high temperatures and low rainfall as compared to annual evapotranspiration, which facilitated the accumulation of calcium carbonate in these soils.

The variation in calcium carbonate content among the villages might be due to variation in pH and clay content of the soils present in that area. Calcium carbonate content of soils exhibited significant positive correlation (0.298*) (table 4.9) with clay content and positive correlation pH (0.360**) which showed evidence that clay and pH hadinfluenced calcium carbonate content. Similar relationships between calcium carbonate content and clay and pH were earlier observed by Singh *et al*. (2012) in different agro climatic zones of Punjab.

Cation exchange capacity

The perusal of data presented in table 4.4 revealed that cation exchange capacity (CEC) of different soils of Sattenapalli mandal was high and it varied from 32.61 to 52.17 with a mean value of 42.90cmol(p+) kg^{-1}soil. The high CEC values of these soils might show due to clay texture of majority of the soils. The CEC of soils was found to be strong positive correlation(r=0.529**) (table 4.9) and regression (R^2=0.279) (figure 4.7) with clay content of soil. Similar results were earlier reported by Balapande *et al*. (2007) in black soils of Nasik.

Among the villages, lowest mean in CEC value was recorded in soils of Nandigama (37.82cmol (p+) kg^{-1}) while the highest in soils of Bhrugubanda (47.55cmol (p+) kg^{-1})village. The variation in CEC values among the villages might be due to variation in clay and organic carbon content (Maji *et al*., 2001).

Exchangeable bases

The perusal of data presented in table 4.4 indicated that irrespective of location, the soil complex was dominantly saturated with calcium followed by magnesium, sodium and potassium.

Thangaswamy *et al.* (2005) reported similar sequence of saturation with bases on soil complex. The low values of monovalents (Na^+ and K^+) compared to divalents (Ca^{2+} and Mg^{2+}) were due to dominance of calcium and magnesium rich parent materials and also the monovalents were leached out easily than divalents because divalents were relatively immobile compared to monovalents (Ravikumar, 2009)

The exchangeable calcium was found to be the most dominant cation on the exchangeable complex with a range of 24.51 to 38.15 cmol (p+) kg^{-1} of soil with a mean value of 30.98 cmol (p+) kg^{-1}. The higher exchangeable calcium content might be due to the presence of free calcium carbonate in some soils of the study area. This was evidenced by significant positive correlation of calcium carbonate with exchangeable Ca^{+2}(r=0.450**) (table 4.9) and regression coefficient (R^2) of 0.182 as depicted in the figure 4.10.

Exchangeable magnesium was the second most dominant cation next to calcium and it varied from 3.36 to 13.63 cmol (p+) kg^{-1} with a mean value of 7.92 c mol (p+) kg^{-1} (Table 4.4). Similar results were observed by Ram *et al.* (2010) in eastern plains of Rajastan.

The exchangeable sodium and potassium contents ranged from 0.33 to 2.01 and 0.14 to 0.82 cmol (p+) kg^{-1} with mean values of 1.00 and 0.55 cmol(p+) kg^{-1},respectively. The content of potassium was least among the cations, which might be due to slow weathering of minerals and also due to fixation of released potassium.

Saturation of exchangeable basic cations

The exchangeable soil complex was highly saturated with exchangeable calcium with an overall range of 58.30 to 80.07% of soil with a mean value of 72.42 per cent. The higher per cent saturation of exchangeable calcium content on the exchangeable complex might be due to the presence of free calcium carbonate in soils of the study area. This was evidenced by significant positive correlation of calcium carbonate with exchangeable Ca^{+2}(r=0.450**) (table 4.9) and regression coefficient (R^2) of 0.182 as depicted in the figure 4.10.

Per cent saturation of exchangeable magnesium was next to calcium and it varied from 8.26 to 28.96 %with a mean value of 16.48 % (Table 4.5). Similar results were observed by Medhe *et al.*, (2012).

The per cent saturation of exchangeable sodium and potassium was ranged from 1.01 to 4.42 and 0.43 to 1.82 % with mean values of 2.28 and 1.19%,respectively. The per cent saturation of potassium was least among the cations, which might be due to slow weathering of minerals and also due to fixation of released potassium.

Base saturation

The per cent base saturation of soils ranged from 86.66 to 98.73 with a mean value of 92.38. The highest (98.73) and lowest (86.66) values were observed in soils of Nadigama and Bhatluru villages, respectively (Table 4.5).

Similar results were observed by Varaprasadrao *et al.* (2008) in black soils of Ramachandrapuram mandal of Chittoor district in Andhra Pradesh. High base saturation might be due to moderately alkaline reaction, $CaCO_3$ content and limited leaching of bases, as the exchangeable complex of the soils were dominated by calcium and magnesium.

4.1.2 Available Nutrient Status of the Calcareous soils of Sattenapalli Mandal

4.1.2.1 Macro nutrients

Nitrogen

The range and mean of available nitrogen content of calcareous soils of each village and the nutrient index are presented in table 4.6 and 4.16.

The available nitrogen content of calcareous soils ranged from 142.06 to 292.65kg ha^{-1} with a mean value of 221.76 kg ha^{-1}. Among the 50 samples, 92% were found to be low in available nitrogen content. Low available nitrogen in these soils was due to low organic carbonand high $CaCO_3$content as revealed by significant positive correlation (r=0.458**) (table 4.9) and regression(R^2=0.135) (figure 4.11) with organic carbon and significant negative correlation between available $CaCO_3$ and N (r=-0.327*) (table 4.9). The semi-arid conditions of the area might have favoured the rapid oxidation and less accumulation of organic matter releasing more NO_3-N, which could have been lost by leaching, which was in accordance with the earlier reports of Revathi *et al*. (2005) and Srinivas *et al*. (2011). Growing of exhaustive crops like cotton, rice and maize with limited addition of nitrogen through organics also might be the reason for low nitrogen status of the study area. The low N content in calcareous soils was because of more volatilization losses. Similar losses were reported in some Vertisols of Andhra Pradesh (Vijayasankarbabu *et al.*, 2006).

The highest mean innitrogen content was recorded in soils of Nandigama village (249.52 kg ha^{-1}), while the lowest was noticed insoils of Bhrugubanda village (191.96kg ha^{-1}).

Phosphorus

Based on P_2O_5 content and categorization of soils into low, medium and high are presented in table4.6 and 4.8, respectively.

The P_2O_5 content in calcareous soils of Sattenapalli mandal ranged from 11.00 to 75.24 kg ha^{-1} with a mean value of 28.53 kg ha^{-1}. Out of 50 soil samples, 44 per cent were under low (<22.4 kg P_2O_5 ha^{-1}), 54 per cent were under medium (22.4 – 56 kg P_2O_5 ha^{-1}) and only 2 per cent were under high(>56 kg P_2O_5 ha^{-1}) in available phosphorus as per the ratings provided by Muhr *et al.* (1965).

Similar trend with respect to phosphorus was earlier reported by Senapathi (2011) in cotton growing soils of Guntur division of Guntur district. Available phosphorus content calcareous soils of study area exhibited significant positive correlation (r = 0.386**) with organic carbon and significant negative correlation (r =- 0.340*) with calcium carbonate (Table 4.9).In accordance with this, the regression coefficients also proved that the available phosphorus had positive relationship with organic carbon (R^2=0.096) (figure 4.12) and negative relationship with calcium carbonate(R^2=0.091) (figure 4.13), which showed evidence that organic carbon and calcium carbonate had influencedthe available phosphorus content of calcareous soils of study area. Vijayasankar Reddy and Seshagiri Rao, (1991) observed strong negative correlation (r=-0.829*) between P and $CaCO_3$ contents of calcareous vertisols in Rayalaseema region of A.P. Similar relationships between available phosphorus content and organic carbon and calcium carbonate were earlier observed by Muhr *et al* (1965).

Among the different villages, highest (44.40 kg ha^{-1}) mean value of available P_2O_5 content was observed in soils of Kantepudi village while the lowest (16.42 kg ha^{-1}) was observed in soils of Gandluru village.

Potassium

The data pertaining to the available potassium content (expressed as kg K_2O ha^{-1}) of soil samples of each village and their distribution into low, medium and high status of the soils are presented in table 4.6 and 4.8, respectively.The average availableK_2O content of calcareous soils varied from 152.61 to 709.43 kg ha^{-1} with mean value of 451.31 kg ha^{-1}.

Out of 50 samples, 80 per cent samples were under high (>336 kg ha^{-1}), 18 per cent were under medium (168-336 kg ha^{-1}) while remaining 2 per cent were under low (<168 kg ha^{-1})in available K_2O. A significant positive correlation (r=0.302*) (table 4.9)and a positive regression coefficient (R^2=0.092) (figure 4.14) was observed between calcium carbonate and K_2O content of the study area. This showed evidence that available potassium content of soils increased with calcium carbonate content of the soils.

Similartrend with respect to available potassium was earlier reported by Jadav *et al.*(1993). He revealed that potassium release increased up to 30 per cent lime in soil, maintained same level up to 40 per cent and there after that level of available K content decreased.

The fertility status of soils of the study area with respect to nitrogen, phosphorus and potassium is depicted in figure 4.6.

Sulphur

The available sulphur content of soil samples of each village and categorization of soils into low, medium and high are presented in table 4.6.

The sulphur content in calcareous soils of Sattenapalli mandal ranged from 8.12 to 27.09ppm with a mean value of 15.70ppm. Out of 50 soil samples, 6 per cent of samples were under low (<10ppm), 80 per cent were under medium (10-20ppm) and only 14 per cent were under high(>20ppm) in available sulphur as per the ratings proposed by Gupta*et al*. (2012). Among the different villages, highest mean (17.90 ppm) value of available sulphur content was observed in soils of Komerapudi village while the lowest mean value (12.24ppm) was observed in soils of Bhatluru village.

Available sulphur content of calcareous soils of study area exhibited positive correlation with organic carbon. Similar trend and relationship between available sulphur content and organic carbon were earlier observed by Narale *et al*. (2015).

Among the different villages of study area only soils of Bhrugubanda, Kantepudi and Pakalapadu village samples showed deficiency in sulphur (<10ppm) content.

4.1.2.2 Micronutrients

The data pertaining to the range and mean contents of availablezinc, iron, manganese, copper and boronare presented in the table 4.7.

The results revealed that the order of mean (ppm) status of available micronutrients was found to be Fe (12.01) > Mn (6.89) > Cu (1.92) > Zn (0.50)>B (0.42).

Zinc

The data presented in table 4.6 indicated that the DTPA extractable zinc content of soil samples ranged from 0.20 to 1.52 ppm with a mean of 0.51 ppm, which was below the critical level (0.8ppm). It was observed that the deficiency of zinc was pronounced in calcareous soils of all the villages of the mandal (Figure 4.6). Out of 50 calcareous soil samples, 88 per cent of samples were below the critical limit while the rest of the soils (12 %) were above critical limit. Hundred per cent deficiency was observed in soils of Pedamakkena, Kantepudi, Bhrugubanda, Bhatluru, Abburu, Kattamuru and Gandluru.Similar range of DTPA extractable zinc was reported by Kumar and Babel (2010).

The deficiency of zinc in majority calcareous soils of the study area might be due to high calcium carbonate and low organic carbon content of the soils.

The calcium carbonate content of soils had significant negative effect (r = -0.327*) (R^2=0.118) on available zinc contentas presented in the table 4.9 and depicted in figure 4.15 respectively. It seems that the calcium carbonate induced the formation of insoluble compounds of zinc such as zinc hydroxide or zinc carbonate and thus resulted in reduced availability as reported by Vijayashekar *et al.* (2000), Mathur *et al.* (2006) and Ravikumar *et al.* (2007). Similar relationship between available zincand calcium carbonate was observed by Sharma *et al.* (2003) and Mahashabde and Patel (2012) in Shirpurtahsil of Maharashtra. Hence it was considered as lime induced Zn deficiency

The organic carbon was positively and significantly related (r=0.348*) with the availability of zinc in these soils as shown in table 4.9. In accordance with that regression also proved a positive (R^2=0.116) relationship between organic carbon and Zn (figure 4.17). Since, the surveyed soils were low in organic carbon also low in available zinc status. Similarly, Mathur *et al.* (2006) reported that soils showing deficiency in available zinc were recorded low in organic carbon content.

Iron

In general, the soils of the study area were sufficient with respect to available iron content and it ranged from 2.37 to 35.09 ppm with a mean value of 11.00 ppm as given in table 4.7. Available iron content of present soils was within ranges reported earlier by Gupta *et al.* (2000).

As per the limits given by Lindsay and Norvell (1978) about 84.00 per cent of samples were recorded well above the critical limit (>4.5 ppm) with no deficiency insoils of Nandigama, Abburu, Kattamuru and Gandluru villages. However, a slight deficiency of 10.00 per cent was found insoils of Komerapudi, Pedamakkena, Gudipudi, Kantepudi, Bhrugubanda and Bhatluru villages. The organic carbon influenced the availability of iron by chelating action could be protected the iron from oxidation and precipitation, which consequently increased the availability of iron in the surface soils and iron content of calcareous soils had significant positive correlation with organic carbon (r=0.308*)(table 4.9). In some calcareous soils Prasad and Sakal, (1991) reported that sufficiency of iron in majority of soils might be due to its chelation with organic carbon of the soils.

The available ironcontent andvalues of calcium carbonate contentin these soils had a negative relationship(r = -0.293*, R^2=0.082, Table 4.9, figure 4.18). The significant and negativecorrelation of iron content with calcium carbonate was also observed by Sharma and Kanwar (2010)in pea growing soils of Himachal Pradesh.The negative correlation of iron with calcium carbonate was due to higher oxidation potential of Ca^{2+} in comparison to Fe^{2+}.

Manganese

The results presented in table 4.7 indicated that the DTPA extractable manganese content of soils varied from 1.98 to 10.99 ppm with a mean value of 6.67 ppm.

The soils were sufficient in available manganese content and 98.00 per cent samples were found to be well above the critical limit (2ppm) as per the ratings of Lindsay and Norvell (1978). The results were corroborated with the findings of Yadav (2011) in arid region of western Rajasthan.

Among the villages, the highest and lowest mean content of manganese was recorded in soils of Nandigama (8.57 ppm) and Kantepudi (5.57ppm) villages, respectively. Sufficient amounts of available manganese in soils of Karnataka were reported by Vijayshekar *et al.* (2000). Highest concentration of available manganese might be due to the chelation effect of organic compound (Verma *et al.*, 2007). The parent material rich in manganese bearing minerals was responsible for the high content of manganese in soils of the study area.

Copper

The data pertaining to range and mean of DTPA extractable copper content of soils are presented in table 4.7.

The DTPA extractable copper content of soils ranged from 0.18 to 5.42ppm with mean of 1.88 ppm. Considering the critical limits of DTPA extractable copper (0.2ppm) in soil, all the soils were adequately supplied with copper.

Among the villages, the highest and lowest means were observed in soils of Nandigama (4.01ppm) and Kantepudi (1.10ppm), respectively.

The higher copper content of soils might be due to application of copper fungicides and release from weathering of Cu-minerals (Vijayasekhar *et al.*, 2000). Further, it was attributed to their chelation with organic compounds leading to increase in their availability.

The available copper was significantly positively correlated with nitrogen (r = 0.413**) and significantly negatively related to$CaCO_3$ (r = -0.355**)(Table 4.8) (R^2=0.088) (figure 4.19). The results were in conformity with the findings of Vijaykumar *et al*. (2011) and Rao, (2013) in south east coastal soils of India and forest soils of Talakona in Chittor district, Andhra Pradesh, respectively.

Boron

The data presented in table 4.6 indicated that the hot water extractable boron (HWEB) content of calcareous soil samples ranged from 0.07 to 1.50 ppm with a mean of 0.42 ppm, which was below the crtical level (0.50ppm). It was observed that the deficiency of boron was pronounced in calcareous soils of all the villages of the mandal (Figure 4.24). Out of 50 calcareous soil samples, 64 per cent of samples were below the critical limit while the rest of the soils (36 %) were above critical limit. Similar range of available boron was reported by Kumar and Babel (2010) in calcareous soils of Jhunjhunu district Rajastan.

The deficiency of available boron in majority calcareous soils of the study area might be due to high calcium carbonate, clay, pH and low organic carbon content of thesoils.

The negative relationship between soil B and pH of soil (r=-0.318*) (R^2=0.092) which clearly exhibited that as the pH of soil increased, the availability of B decreasedas presented in the table 4.9 and depicted in the figure 4.20. These results were also supported by (Lehto, 1995) and Niaz *et al*. (2007).

The results revealed that there was strong negative correlation (r = -0.593**) (table 4.9) and regression (R^2=0.361) (figure 4.21) between soil available B and $CaCO_3$ contents of soil. The adsorption of B on $CaCO_3$ was more which resulted into less availability of B in calcareous soils. A promising reason for the increase in adsorption of B on $CaCO_3$ was the bonding of B with calcium carbonate ($CaCO_3$). This could be escorted to the precipitation of calcium-borate, substitution of carbon by boron in $CaCO_3$ or simple surface adsorption of B on $CaCO_3$.Similar kind of results were reported by Goldberg(1993) and Niaz *et al*. (2007).

Organic matter is an important soil constituent affecting the availability of B.The organic carbon was positively and significantly related (r = 0.377**) with the availability of boron in these soils as shown in table 4.9. Correlation and regression (R^2=0.127) (Figure 4.22) analysis showed that soil B had positive correlation with SOM and with increase in SOM content, B concentration augmented as well and this boost might be due to the decomposition of OM.There by producing of certain organic acids like tartaric, oxalic, citric, acetic, formic, fluvic and humic acid solublized the unavailable fixed B or adsorbed B on clay or $CaCO_3$. The surveyed soils were low in OM and also low in available boron status. Similar kind of results were reported by Niaz *et al.* (2007).

The results revealed that there was a negative correlation (r = -0.316*)and regression (R^2=0.104) between soil available B and clay contents of the calcareous soils as presented in the table 4.9 and depicted in thefigure 4.23. Textural analysis exhibited that the soils of study werebasically clay textural class, which indicated that soils were deficient in available boron status because of the strength by which B was strongly held on clay surfaces Niaz *et al.* (2007).

4.2 POT CULTURE EXPERIMENT

4.2.1 Effect of levels of B on total bio-mass production and seed yield of blackgram grown in calcareous soils collected from Sattenapalli mandal of Guntur district

4.2.2 Effect of levels of B on nutrient content of blackgram grown in calcareous soils collected from Sattenapalli mandal of Guntur district

4.2.3 Effect of levels of B on nutrient uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal of Guntur district

4.2.1. Total Bio-Mass Production and Seed Yield of Blackgram Grown in Calcareous Soils Collected from Sattenapalli Mandal of Guntur District

4.2.1.1 Effect of levels of B on total bio-mass production of blackgram grown in calcareous soils collected from Sattenapalli mandal of Guntur district

The performance of blackgram crop with respect to biomass production in pot culture experiment with the application of boron in different calcareous soils are presented in table 4.10 and depicted in the figure 4.25.

Different soils irrespective of B levels were effective in influencing biomass production of blackgram. The mean biomass production by blackgram decreased significantly from S_1 (4.58g pot^{-1}) to S_5 (2.72g pot^{-1}) soil except for S_2. Highest (4.58g pot^{-1}) biomass production was observed in S_1 (containing 1.08% $CaCO_3$) soil and was on par with S_2 (4.48g pot^{-1}) which contained 5.25% $CaCO_3$ and lowest (2.72g pot^{-1}) was observed in S_5 (containing 17.75% $CaCO_3$) soil. Soils having different calcium carbonate content behaved differently for biomass production. The results indicated that soils having calcium carbonate up to 5 per cent as in present case normally did not affect the biomass production significantly.

The applied doses of boron increased the biomass production significantly over control. Irrespective of soil type, there was significant variation in biomass production by blackgram due to different rates of boron application. Soil applied B at 0.5 mg pot^{-1} (B_2) was adequate to cause significant increase in biomass production regardless of type of soil. Highest (3.89g pot^{-1}) mean biomass production by blackgram was observed in B_3 level while lowest (3.24g pot^{-1}) was in B_0 (control). Similar results were recorded by Hussain *et al.* (2008) in mustard. The improvement in biomass production can be attributed to the role of B in stabilizing certain constituents of cell wall and plasma membrane, enhancement of cell division, tissue differentiation and metabolism of nucleic acids, carbohydrates, proteins, auxins and phenols (Marschner, 1986).

The interaction between boron application and soil influenced the biomass production by blackgram. Biomass production by blackgram ranged from 2.58 at S_5B_0 to 4.90 g pot^{-1} at S_1B_2 treatment. Highest (4.90 g pot^{-1}) biomass production was observed at S_1B_2 which was on par with S_1B_1 (4.76 g pot^{-1}) and S_2B_3 (4.88 g pot^{-1}) treatment. Lowest (2.58 g pot^{-1}) biomass production was observed at S_5B_0 which was on par with S_5B_2 (2.68 g pot^{-1}) treatment (Table 4.10) (Figure 4.25). The results were in accordance with the findings of Padbhushan and Kumar (2014) on greengram in calcareous soils. The treatment S_1B_3 (S_1 soil which containing 1.08% CaCO3 that received B @ 0.75 mg kg^{-1}) showed a toxic effect and resulted in decrease in biomass production (4.66 g pot^{-1}). The decrease in biomass production with increasing B might be due to the toxicity effect of higher dose of B application in soil. The detrimental effects of the highest B application on biomass production were also observed by Raza *et al.* (2014) in wheat crop grown in calcareous soils of Pakistan.

4.2.1.2 Effect of levels of B on seed yield of blackgram grown in calcareous soils collected from Sattenapalli mandal of Guntur district

The performance of blackgram crop with respect to seed yield in pot culture experiment with the application of boron in different calcareous soils are presented in table 4.11 and depicted in the figure 4.26.

The mean seed yield of blackgram grown in five different calcareous soils irrespective of B levels decreased significantly with increase in calcium carbonate content of the soil except for the S_2-soil. The maximum mean seed yield (1.99 g pot^{-1}) was recorded in S_1 with low calcium carbonate content (1.08% $CaCO_3$) which was on par with the S_2-soil (1.92 g pot^{-1}) which contained 5.25% $CaCO_3$. The minimum mean seed yield (1.99 g pot^{-1}) was observed in S_5 with high calcium carbonate content (17.75% $CaCO_3$). At varied levels of calcium carbonate content of soils, the per cent decrease in seed yield over S_1-soil was 3.52, 26.63, 35.67 and 41.20 at S_2, S_3, S_4 and S_5, respectively. These results were accordance with the findings of Padbhushan and Kumar (2014).

The applied doses of boron increased the mean seed yield significantly over control. Irrespective of soil calcium carbonate content, there was a significant variation in mean seed yield of blackgram due to different levels of boron application. Among the different levels of boron, application of 0.75 mg B kg^{-1} of soil resulted the maximum in mean seed yield (1.67 g pot^{-1}). The minimum mean seed yield (1.40 g pot^{-1}) was recorded in control (0 mg B kg^{-1}). At varied levels of boron, the per cent increase in seed yield over control was 10.71, 16.43 and 19.29 at B_1, B_2 and B_3, respectively. This improvement in yield could be ascribed to boron as it was directly linked with process of fertilization, pollen producing capacity of anther, viability of pollen grains, pollen germination and pollen tube growth (Dickinson, 1978; Agarwal *et al.*, 1981; Vaughan, 1997). Similar results were reported by Kaisher *et al.* (2010) in greengram.

Combined effect of boron application and soils showed an influence regarding seed yield of blackgram. Maximum seed yield (2.14 g pot^{-1}) was recorded under interaction of 0.50 mg B kg^{-1} of soil (B_2) for S_1 - soil (1.08% calcium carbonate) which was on par with S_1B_1, S_1B_3, S_2B_2, and S_2B_3 and minimum seed yield (1.11 g pot^{-1}) was observed under interaction of 0 mg B kg^{-1} of soil (B_0) for S_5 - soil (17.75% calcium carbonate) which was on par with S_4B_0, S_5B_1, S_5B_2, and S_5B_3. The similar trends were observed by Ziaeyan and Rajaie (2009) in corn crop grown under high calcium carbonate soil fertilized with B application. The detrimental effects of the highest B application on seed yield (2.0g pot^{-1}) was also observed in the treatment S_1B_3 (S_1 soil containing 1.08% CaCO3 that received B @ 0.75 mg kg^{-1}). Similar results were earlier reported by Raza *et al.* (2014) in wheat crop grown in calcareous soils of Pakistan. The decrease in seed yield with increasing B doses might be due to the toxicity effect of higher dose of B application in soil.

4.2.2. Effect of Levels of B on Nutrient Content of Blackgram Grown in Calcareous Soils Collected from Sattenapalli Mandal of Guntur District

4.2.2.1 Effect of levels of B on nitrogen content of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

Results pertaining to the effect of levels of boron on nitrogen content of blackgram grown in calcareous soils are presented in the table 4.12 and depicted graphically in figure 4.27.

Soils (S_1 to S_5) with varied levels of calcium carbonate content (1.08, 5.25, 10.37, 16.20 and 17.75% $CaCO_3$) had significant influence on nitrogen content of blackgram. Nitrogen content of blackgram decreased significantly with increase in calcium carbonate content of soils except for the S_2 soil. Maximum nitrogen content (3.10%) in blackgram was observed in S_1 soil which was on par with S_2 soil and minimum nitrogen content (2.36%) was observed in S_5 soil. At varied levels of calcium carbonate content of soils from S_2 to S_5, per cent decrease was 0.65, 6.45, 17.42 and 23.87 respectively, over S_1 soil containing 1.08 $CaCO_3$% . This decrease in nitrogen content might be due to the alkaline pH value found in calcareous soils that affected the rate of N transformations, which in turn influenced the efficiency of N use by plants (Wiezler, 1998).

Nitrogen content of blackgram increased progressively at varied levels of boron and the difference recorded over control (B_0) was significant. Maximum nitrogen content (2.91%) of blackgram was recorded in B_3 level (0.75 mg pot^{-1})

while minimum nitrogen content (2.65%) of blackgram was recorded in control (B_0). At varied levels of boron, the per cent increase in nitrogen content was 4.91, 7.92 and 9.81 at B_1, B_2 and B_3 respectively, over control (B_0). Similar results were reported by Shamsuddoha *et al.* (2011). Boron had increased nodulation activity which might have increased the nitrogen content. Moreover, application of boron in boron deficient soil might have resulted in increased availability of boron which in turn influenced DNA and protein synthesis leading to increased nitrogen content (Yakuba *et al*., 2010; Debnath and Ghosh, 2011).

Interaction effect between applied boron and soils increased the nitrogen content in blackgram crop. Maximum nitrogen content (3.24%) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with $S_1B_{1,}$ S_1B_3 and S_2B_3 treatments. Minimum nitrogen content (2.31%) was observed under interaction of 0.00 mg B kg^{-1} (B_0) of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2 treatments. Similar results were reported by Padbhushan and Kumar (2014) in greengram grown in calcareous soils.

4.2.2.2 Effect of levels of B on phosphorus content of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

Data (Table 4.13 and Figure 4.28) regarding phosphorus content of blackgram as affected by graded levels of boron application to calcareous are discussed below

Soils (S_1 to S_5) with varied levels of calcium carbonate content of 1.08, 5.25, 10.37, 16.20 and 17.75%, respectively had significant influence on phosphorus content of blackgram. Phosphorus content of blackgram decreased significantly with increase in calcium carbonate content of soils except for the S_2 soil. Maximum phosphorus content (0.41%) in blackgram was observed in S_1 level which was on par with S_2 level and minimum in phosphorus content (0.19%) was observed in S_5 level. At varied levels of calcium carbonate content of soils, per cent decrease over S_1 was 2.43, 19.53, 39.02 and 53.65, at S_2, S_3, S_4 and S_5, respectively (Table 4.13, Figure 4.28). Phosphorus availability in calcareous soils is usually restricted. In calcareous soils, phosphate ions react with Ca and Mg to form phosphate compounds (calcium phosphate) of limited solubility which in turn reduced available phosphorus to plants ultimately reduced the phosphorus content of plants (Mortvedt *et al.*, 1999).

Phosphorus content of blackgram increased progressively at varied levels of boron and the difference recorded over control (B_0) was significant. Maximum phosphorus content (0.36%) of blackgram was recorded in B_3 level while minimum phosphorus content (0.26%) of blackgram was recorded in control (B_0). At varied levels of boron (B_1 to B_3), the per cent increase in phosphorus content over control (B_0) was 15.38, 26.92 and 38.46, respectively (Table 4.13, Figure 4.28). Similar results were reported by Shamsuddoha *et al.*, (2011). Increase in the phosphorus content with the increase in boron application could be due to favourable influence of boron on various metabolic processes like photosynthesis, respiration, enzyme activity (Ganie *et al.*, 2014) which augmented the production of metabolites and their translocation to different parts including seed which ultimately increased the concentration of nutrients in plant.

Combined effect of boron application and soils showed an influence regarding phosphorus content of blackgram. Maximum phosphorus content (0.46%) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 - soil (1.08% calcium carbonate) which was on par with S_1B_1 and S_2B_3. Minimum phosphorus content (0.16%) was observed under interaction of 0.00 mg B kg^{-1} of soil for S_5 - soil (17.75% calcium carbonate) which was on par with $S_5B_{1,}$ $S_5B_{2,}$ and S_4B_0 (Table 4.13) (Figure 4.28). Similar results were reported by Padbhushan and Kumar, (2014) on greengram grown in calcareous soils.

4.2.2.3 Effect of levels of B on potassium content of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The results presented in table 4.14 and depicted graphically in figure 4.29indicated the effect of levels of boron on potassium content of blackgram grown in calcareous soils.

Irrespective of levels of boron application the potassium content of blackgram decreased significantly with increase in calcium carbonate content of soils (S_1 to S_5) except for the S_2 soil. Maximum potassium content (3.39%) in blackgram was observed in S_1 (containing 1.08% $CaCO_3$) soil which was on par with S_2 soil and minimum in potassium content (1.35%) was observed in S_5 soil which contained 17.75% $CaCO_3$. At varied levels of calcium carbonate content of soils, per cent decrease over S_1 was 2.94, 23.89, 38.05 and 60.87 at S_2, S_3, S_4 and S_5, respectively. Available K was usually found in an adequate supply in calcareous soils. This was due to native high levels of exchangeable K, which was hardly leached in low rainfall regions and an imbalance between plant available Mg, Ca and K ions may lead to reduced K use efficiency by crops in calcareous soils (Brady and Weil, 1999) and Jadav *et al.* (1993) studied the K dynamics under different degree (native lime 4% plus 10, 20, 30, 40 and 50% CaCO3) of calcareousness using maize as a test crop. It indicated that K content decreased with increase in $CaCO_3$ levels.

Potassium content of blackgram increased progressively at varied levels of boron and the difference recorded over control (B_0) was significant. Maximum potassium content (2.77%) of blackgram was recorded in B_3 level while minimum potassium content (2.28%) of blackgram was recorded in control (B_0). At varied levels of boron, the per cent increase in phosphorus content over control was 8.77, 16.23 and 21.49 at B_1, B_2 and B_3, respectively. Similar results were reported by Niaz *et al.* (2011). The increase in the content of potassium by boron fertilization could be attributed to better growth of crop resulting in greater absorption of nutrients from soil leading to its higher content. The synergistic interaction between K and B also reported by Sakal *et al.* (1988).

Interaction effect between applied boron and soils was conspicuous on the potassium content of blackgram crop. Maximum potassium content (3.62%) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with S_1B_1 and S_2B_3. Minimum potassium content (2.31%) was observed under interaction of 0.00 mg B kg^{-1} of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1. These results were in accordance with that of Patel and Golakiya (1986).

4.2.2.4 Effect of levels of B on sulphur content of blackgram grown in calcareous soils collected fom Sattenapalli mandal, Guntur district

Results pertaining to the effect of levels of boron on sulphur content of blackgram grown in calcareous soils are presented in the table 4.15 and depicted graphically in figure 4.30.

Sulphur content of blackgram grown in five different calcareous soils irrespective of B levels, decreased significantly with increase in calcium carbonate content of the soil except for the S_2 soil. Maximum sulphur content (0.42 ppm) in blackgram was observed in S_1 level which was on par with S_2 (0.41ppm) soil and minimum in sulphur content (0.23 ppm) was observed in S_5 soil. At varied levels of calcium carbonate content of soils, per cent decrease over S_1 (containing1.08% $CaCO_3$) was 2.38, 30.95, 40.47 and 45.23, at S_2, S_3, S_4 and S_5, respectively.

Sulphur content of blackgram increased progressively at varied levels of boron irrespective of calcium carbonate content of soil and the difference recorded over control (B_0) was significant. Maximum sulphur content (0.35 ppm) of blackgram was recorded in B_3 level while minimum sulphur content (0.28 ppm) of blackgram was recorded in control (B_0). At varied levels of boron (B_1 to B_3), the per cent increase in sulphur content over control (B_0) was 14.29, 21.43 and 25.00 respectively. These results were in accordance with Debnath *et al.* (2011). The increase in the content of sulphur by boron fertilization could be attributed to better growth of crop resulting in greater absorption of nutrients from soil leading to its higher content.

Combined effect boron application and soils showed an influence regarding the sulphur content of blackgram. Maximum sulphur content (0.46 ppm) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_0) of soil for S_1 level (1.08% calcium carbonate) which was on par with S_1B_1 and S_2B_3. Minimum sulphur content (2.31 ppm) was observed under interaction of 0.00 mg B kg^{-1} of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2. Similar results were reported by Debnath *et al.* (2011).

4.2.2.5 Effect of levels of B on zinc content of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The performance of blackgram crop with respect to Zn content, grown in pot culture experiment with the application of boron in different calcareous soils are presented in table 4.16 and depicted in the figure 4.31.

Different soils irrespective of B levels were effective in influencing the zinc content of blackgram. Zinc content of blackgram decreased significantly with increase in calcium carbonate content of soils except for the S_2 soil. Maximum zinc content (62.79 ppm) in blackgram was observed in S_1 (containing 1.08% $CaCO_3$) soil which was on par with S_2 (60.01 ppm) soil which contained 5.25% $CaCO_3$ and minimum zinc content (33.59 ppm) was observed in S_5 (containing 17.75% $CaCO_3$) soil. At varied levels of calcium carbonate content of soils, per cent decrease over S_1 was 4.42, 17.42, 33.74 and 46.50, at S_2, S_3, S_4 and S_5, respectively. In calcareous soils due to high $CaCO_3$ of soils, Zn ions present in the soil adsorbed on the finer particles of $CaCO_3$ or it formed zinc carbonates which were unavailable to plants and in turn reduced the zinc content in plants (Savithri and Chitdeshwari, 2000).

Zinc content of blackgram increased progressively at varied levels of boron and the difference recorded over control (B_0) was significant. Maximum zinc content (54.89 ppm) of blackgram was recorded in B_3 level while minimum zinc content (44.00 ppm) of blackgram was recorded in control (B_0). At varied levels of boron, the per cent increase in zinc content over control was 11.09, 18.43 and 24.75 at B_1, B_2 and B_3, respectively. Niaz *et al.* (2011) reported synergistic relationship between B and Cu. These results were coincided with the findings of Shaaban *et al.* (2004) in wheat with application of B.

Interaction effect between applied boron and soils was noticed on the zinc content in blackgram crop. Maximum zinc content (66.60 ppm) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with S_1B_1 and S_2B_3. Minimum zinc content (30.12) was observed under interaction of 0.00 mg B kg^{-1} (B_0) of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2. Similar results were reported by Waghadhare *et al.*, (2007). Decrease in the Zn content was also observed at higher doses of B. Such observations were earlier made by Aref (2012) in maize crop. Boron application in large amounts might have caused antagonism and thus reduced the leaf Zn concentration.

4.2.2.6 Effect of levels of B on iron content of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The iron content of blackgram with varied levels of boron application in calcareous soils are presented in the table 4.17 and depicted graphically in figure 4.32.

Calcium carbonate content of soils from S_1 to S_5 had significant influence on iron content of blackgram. Iron content of blackgram decreased significantly with increase in calcium carbonate content of soils except for the S_2 (5.25% $CaCO_3$) soil. Maximum iron content (583.72 ppm) in blackgram was observed in S_1 level which was on par with S_2 level and minimum in iron content (322.95 ppm) was observed in S_5 level. At varied levels of calcium carbonate content of soils, per cent decrease was 3.65, 15.02, 28.36 and 44.67, at S_2, S_3, S_4 and S_5, respectively over S_1 which contained only 1.08% $CaCO_3$. In calcareous soils, the solubility of iron was low due to the high carbonate content which in turn reduced the availability of iron to plants in calcareous soils (Singh and Joshi,

2000) and also calcareous soils might contain high levels of total Fe, but in forms unavailable to plants. Iron was less soluble in soils with a pH value 8 and above; thus, inorganic Fe contributed little to the iron nutrition of plants in calcareous soils. The primary factor reducing the Fe absorption by plants in calcareous soils was bicarbonate ions (Bavaresco *et al.*, 1999). Thus the iron content of plants decreased with increase calcium carbonate content of soils.

Iron content of blackgram increased progressively at varied levels of boron and the difference recorded over control (B_0) was significant. Maximum iron content (513.13 ppm) of blackgram was recorded in B_3 level while minimum iron content (434.48 ppm) of blackgram was recorded in control (B_0). At varied levels of boron from at B_1 to B_3, the per cent increase in iron content over control (B_0) was 6.41, 14.30 and 18.10, respectively. Alveraz-Tinaut (1990) found a positive relation between B and Fe. They suggested that B could indirectly affect catalase activity via Fe. Similar results were reported by Niaz *et al*. (2011).

Interaction effect between applied boron and soils was noticed on the iron content in blackgram crop. Maximum iron content (621.55 ppm) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with S_1B_1 and S_2B_3. Minimum iron content (30.12 ppm) was observed under interaction of 0.00 mg B kg^{-1} (B_0) of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2. These results were in accordance with the findings of Praba and singaram (1996).

4.2.2.7 Effect of levels of B on manganese content of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The data on manganese content of blackgram grown in calcareous soils with different levels of boron are presented in the table 4.18 and depicted graphically in figure 4.33.

Soils (S_1 to S_5) with varied levels of calcium carbonate content (1.08, 5.25, 10.37, 16.20 and 17.75% $CaCO_3$) had significant influence on manganese content of blackgram. Manganese content of blackgram decreased significantly with increase in calcium carbonate content of soils. Maximum manganese content (278.18 ppm) in blackgram was observed in S_1 (containing 1.08% $CaCO_3$) soil while minimum manganese content (113.19 ppm) was observed in S_5 soil which contained 17.75% $CaCO_3$. At varied levels of calcium carbonate content of soils, per cent decrease over S_1 was 7.62, 24.52, 37.21 and 57.15 at S_2, S_3, S_4 and S_5, respectively. In calcareous soils, the solubility of Mn was low due to the high carbonate content which in turn reduced the availability of Mn to plants in calcareous soils (Singh and Joshi, 2000). Soil pH was the most important factor regulating Mn in calcareous soils. At alkaline pH values, very low levels of soluble Mn are found, and therefore only a negligible amount can be in the form of exchangeable Mn^{2+} which was available to plants (Patricia, 2000).

Manganese content of blackgram increased progressively at varied levels of boron and the difference recorded over control (B_0) was significant. Maximum manganese content (234.75 ppm) of blackgram was recorded in B_3 level while minimum manganese content (176.86 ppm) of blackgram was recorded in control (B_0). At varied levels of boron, the per cent increase in manganese content over control was 11.43, 23.06 and 32.72 at B_1, B_2 and B_3, respectively. Similar results were reported by Niaz *et al.* (2011). Application of boron significantly increased the Mn content over control (Waghadhare *et al.*, 2007).

Interaction effect between applied boron and soils increased the manganese content in blackgram crop. Maximum manganese content (287.86 ppm) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with S_1B_1 and S_2B_3. Minimum manganese content (100.26 ppm) was observed under interaction of 0.00 mg B kg^{-1} (B_0) of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2. Similar results were reported by Zada and Afzal, (1997).

4.2.2.8 Effect of levels of B on copper content of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

Results pertaining to the effect of levels of boron on copper content of blackgram grown in calcareous soils are presented in the table 4.19 and depicted graphically in figure 4.34.

Soils (S_1 to S_5) with varied levels of calcium carbonate content of 1.08, 5.25, 10.37, 16.20 and 17.75% respectively had significant influence on copper content of blackgram. Copper content of blackgram decreased significantly with increase in calcium carbonate content of soils except for the S_2 soil. Maximum copper content (16.70 ppm) in blackgram was observed in S_1 (1.08% $CaCO_3$) soil which was on par with S_2 soil and minimum copper content (9.29 ppm) was observed in S_5 soil which contained 17.75% $CaCO_3$. At varied levels of calcium carbonate content of soils, per cent decrease over S_1 was 3.35, 23.17, 31.13 and 44.37 at S_2, S_3, S_4 and S_5, respectively. Significant negative relationship was found between the $CaCO_3$ and Cu content where the available Cu decreased with increase in $CaCO_3$ content of soils (Vijaykumar *et al.*, 1996).

Copper content of blackgram increased progressively at varied levels of boron and the difference recorded over control (B_0) was significant. Maximum copper content (14.53 ppm) of blackgram was recorded in B_3 level while minimum copper content (11.44 ppm) of blackgram was recorded in control (B_0). At varied levels of boron, the per cent increase in copper content was 15.30, 22.47 and 27.01 at B_1, B_2 and B_3, respectively over control (B_0). Alveraz-Tinaut, (1990) found a positive relation between B and Cu. Similar results were reported by Niaz *et al.* (2011).

Interaction effect between applied boron and soils increased the copper content in blackgram crop. Maximum copper content (18.31 ppm) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with S_1B_1 and S_2B_3. Minimum copper content (8.42 ppm) was observed under interaction of 0.00 mg B kg^{-1} (B_0) of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2.

4.2.2.9 Effect of levels of B on boron content of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The boron content of blackgram with varied levels of boron application in calcareous soils are presented in the table 4.20 and depicted graphically in figure 4.35.

Soils (S_1 to S_5) with varied levels of calcium carbonate content (1.08, 5.25, 10.37, 16.20 and 17.75% $CaCO_3$) had significant influence on boron content of blackgram. Boron content of blackgram decreased significantly with increase in calcium carbonate content of soils. Maximum boron content (19.50 ppm) in blackgram was observed in S_1 soil which contained 1.08% $CaCO_3$ and minimum boron content (8.75 ppm) was observed in S_5 soil (containing 17.75% $CaCO_3$). At varied levels of calcium carbonate content of soils, per cent decrease over S_1 was 7.02, 34.97, 46.97 and 55.12 at S_2, S_3, S_4 and S_5, respectively. In calcareous soils apart from the B adsorption on the finer particles of $CaCO_3$, the excess Ca interfered in the B nutrition of crops. The occurrence of free Ca ions restricted B availability in soils. The co-precipitation of B with $CaCO_3$ can occur in calcareous soils which would affect the B distribution in the liquid phase of soil (Keren and Bingham, 1985). There was an interaction between B availability and the presence of Ca ions. High levels of Ca at high pH reduced the absorption of B by plants (Mortvedt *et al.*, 1999).

Boron content of blackgram increased progressively at varied levels of boron and the difference recorded over control (B_0) was significant. Maximum boron content (16.19 ppm) of blackgram was recorded in B_3 (0.75 mg B kg^{-1}soil) level while minimum boron content (11.47 ppm) of blackgram was recorded in control (B_0). At varied levels of boron (B_1 to B_2), the per cent increase in boron content over control was 11.16, 31.73 and 41.15, respectively. Similar results were reported by Oosterhuis and Zhao (2002). The boron content of crop increased with increase in available boron content in the soil. This increase in available boron content of soil might be due to increased level of boron application to the soil. The transpiration loss resulted in more movement of applied boron with water in the xylem then to phloem but due to phloem immobility of boron, there was more accumulation of boron in plant (Padbhushan and Kumar, 2014).

Interaction effect between applied boron and soils increased the boron content in blackgram crop. Maximum boron content (22.63 ppm) in blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with S_1B_3 and S_2B_3. Minimum boron content (7.86 ppm) was observed under interaction of 0.00 mg B kg^{-1} (B_0) of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2. These results were in accordance with the findings of Padbhushan and Kumar (2014).

4.2.3 Effect of Levels of B on Nutrient Uptake of Blackgram Grown in Calcareous Soils Collected from Sattenapalli Mandal, Guntur District

4.2.3.1 Effect of levels of B on nitrogen uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The data regarding the nitrogen uptake by blackgram was significantly influenced by the application of various doses of boron to soil (Table 4.21 and Figure 4.36).

Irrespective of the graded levels of boron, uptake of N by blackgram was decreased significantly with increase in calcium carbonate content of the soils from S_1 to S_5. Maximum N uptake (142.1321mg pot^{-1}) in blackgram was observed in S_1 soil which contained 1.08% $CaCO_3$ while minimum (64.21mg pot^{-1}) was observed in S_5 soil (containing 17.75% $CaCO_3$) (Table 4.21) (Figure 4.36). The decrease in N uptake with increase calcium carbonate content of soil might be due to decreased availability of N in soil (Singh and Reddy, 2000).

Nitrogen uptake by blackgram increased progressively at varied levels of boron, irrespective of calcium carbonate content of soils and the difference recorded over control (B_0) was significant. Maximum N uptake (115.22 mg pot^{-1}) was observed at B_3 level while minimum N uptake (87.04 mg pot^{-1}) was observed at B_0 level. At varied levels of boron from B_1 to B_3 percent increase over control was 17.51, 27.52 and 32.36, respectively. The increase in N uptake might be due to physiological interaction rather than an effect of B on N and also due to the favourable effect of B on nodulation (Patel and Golakiya, 1986). Similar favourable effect of B on N uptake was also reported by Padbhushan and Kumar (2014).

Interaction effect between applied boron and soils was significant except at S_5. Highest N uptake (158.48 mg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} of soil for S_1 level (1.08% calcium carbonate) which was on par with the S_2B_3. Lowest N uptake (59.49 mg pot^{-1}) was observed under interaction of 0 mg B kg^{-1} of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1. These results were in accordance with the findings of Padbhushan and Kumar (2014).

4.2.3.2 Effect of levels of B on phosphorous uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

Results pertaining to the effect of levels of boron on phosphorous uptake of blackgram grown in calcareous soils are presented in the table 4.22 and depicted graphically in figure 4.37.

Soils (S_1 to S_5) with varied levels of calcium carbonate content (1.08, 5.25, 10.37, 16.20 and 17.75% $CaCO_3$) had significant influence on phosphorous uptake of blackgram. Irrespective of the graded levels of boron, uptake of P by blackgram was decreased significantly with increase in calcium carbonate content of the soils from S_1 to S_5. Maximum P uptake (19.08 mg pot^{-1}) in blackgram was observed in S_1 soil while minimum (5.14mg pot^{-1}) was observed in S_5 soil. Phosphorus absorption and uptake by plants were low in calcareous soils which might due to low availability of phosphorus by forming limited solubility compounds like calcium phosphate or due to adsorption of P on calcium carbonate (Mortvedt *et al.*, 1999).

Phosphorous uptake by blackgram increased at varied levels of boron (B_0 to B_3); irrespective of calcium carbonate content of soils and the difference recorded over control (B_0) was significant. Maximum P uptake (14.54 mg pot^{-1}) was observed at B_3 level while minimum P uptake (8.76 mg pot^{-1}) was observed at B_0 level. At varied levels of boron (B_1 to B_3) per cent increase was 30.36, 53.53 and 65.98, respectively over control (B_0). The increase in P uptake with B application could be contributed to the favourable effect B, which altered the permeability of plasmalemma at the root surface in such a way that P absorption increased (Patel and Golakiya, 1986). Similar results were reported by Debnath *et al.* (2011).

Interaction effect between applied boron and soils was significant except at S_5 level. Highest P uptake (22.36 mg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} of soil for S_1 level (1.08% calcium carbonate) which was on par with S_2B_3. Lowest P uptake (4.13 mg pot^{-1}) was observed under interaction of 0.00 mg B kg^{-1} of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1. These results are in accordance with the findings of Padbhushan and Kumar (2014).

4.2.3.3 Effect of levels of B on potassium uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The data presented in table 4.23 indicating the effect of levels of boron on potassium content of blackgram grown in calcareous soils was depicted graphically in figure 4.37.

Different soils irrespective of B levels were effective in influencing the potassium uptake by blackgram. Uptake of K by blackgram was decreased significantly with increase in calcium carbonate content of the soils from S_1 to S_5. Maximum K uptake (156.01 mg pot^{-1}) in blackgram was observed in S_1 which contained 1.08% $CaCO_3$ while minimum (36.81mg pot^{-1}) was observed in S_5 soil (containing 17.75% $CaCO_3$). Potassium uptake might be reduced in calcareous soils even in the presence of enough K salts due to calcium-potassium antagonism (Singh and Prasad, 2000).

Potassium uptake by blackgram increased progressively at varied levels of boron, irrespective of calcium carbonate content of soils and the difference recorded over control (B_0) was significant. Maximum K uptake (43.16 mg pot^{-1}) was observed at B_3 level while minimum K uptake (31.73 mg pot^{-1}) was observed at B_0 level. At varied levels of boron percent increase over control was 23.27, 38.66 and 46.72 at B_1, B_2 and B_3, respectively. The increase in K uptake with the application of B might be due to the mutual synergistic relationship of B and K (Waghadhare *et al.*, 2007).

Combined effect of boron application and soils showed a significant effect on potassium uptake of blackgram. Interaction effect between applied boron and soils was significant except at S_4 and S_5 level. Highest K uptake (177.35 mg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} of soil for S_1 level (1.08% calcium carbonate) which was on par with the S_2B_3. Lowest K uptake (31.73 mg pot^{-1}) was observed under interaction of 0.00 mg B kg^{-1} of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2. These results were in accordance with the findings of Padbhushan and Kumar (2014).

4.2.3.4 Effect of levels of B on sulphur uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The sulphur uptake of blackgram with varied levels of boron application in calcareous soils are presented in the table 4.24 and depicted graphically in figure 4.38.

Calcium carbonate content of soils from S_1 to S_5 had significant influence on, uptake of S by blackgram. Irrespective of the graded levels of boron, uptake of S by blackgram decreased significantly with increase in calcium carbonate content of the soils from S_1 to S_5. Maximum S uptake (142.13 µg pot^{-1}) in blackgram was observed in S_1 (1.08% $CaCO_3$) soil while minimum (64.21µg pot^{-1}) was observed in S_5 soil (17.75% $CaCO_3$). Being the product of drymatter and nutrient content, uptake also followed the similar trend (Ganie *et al.*, 2014).

Soil applied B was adequate to significant increase in sulphur uptake by blackgram, regardless of calcium carbonate content of soils. Maximum S uptake (115.22 µg pot^{-1}) was observed at B_3 level while minimum S uptake (87.04 µg pot^{-1}) was observed at B_0 level. At varied levels of boron percent increase over control was 17.51, 27.52 and 32.36 at B_1, B_2 and B_3, respectively. The increase in S uptake with B application might be due to the synergism between B and S (Karle and Babula, 1985). These results were in accordance with the findings of Shamsuddoha *et al.* (2011).

Interaction effect between applied boron and soils was significant except at S_4 and S_5 soil. Highest S uptake (158.48 mg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with the S_2B_3. Lowest S uptake (59.49 mg pot^{-1}) was observed under interaction of 0.00 mg B kg^{-1} of (B_0) soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2. Similar results were reported by Debnath *et al*. (2011)

4.2.3.5 Effect of levels of B on zinc uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

Results pertaining to the effect of levels of boron on zinc uptake of blackgram grown in calcareous soils are presented in the table 4.25 and depicted graphically in figure 4.39.

Different soils irrespective of levels of boron were effective in influencing the Zn uptake by blackgram. With increase in calcium carbonate content of the soils from S_1 to S_5, uptake of Zn by blackgram decreased significantly. Maximum Zn uptake (288 µg pot^{-1}) in blackgram was observed in S_1 soil while minimum (91.54µg pot^{-1}) was observed in S_5 soil. In calcareous soils due to high $CaCO_3$ of soils, Zn ions present in the soil adsorbed on the finer particles of $CaCO_3$ or formed zinc carbonate which was unavailable to plants and in turn reduced the zinc uptake by plants (Patricia, 2000).

Zinc uptake by blackgram increased at varied levels of boron from B_0 to B_3, irrespective of calcium carbonate content of soils and the difference recorded over control (B_0) was significant. Maximum Zn uptake (221.39 µg pot^{-1}) was observed at B_3 level while minimum Zn uptake (147.52 µg pot^{-1}) was observed at B_0 level. At varied levels of boron percent increase over control was 25.00, 40.88 and 50.07 at B_1, B_2 and B_3 levels, respectively. The increase in Zn uptake with B application might be due to the synergistic interaction between B and Zn (Waghadhare *et al.*, 2007). These results were in accordance with the findings of Hossain *et al.* (2011).

Interaction effect between applied boron and soils was significant except at S_5 level. Highest Zn uptake (326.16 µg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} of soil for S_1 level (1.08% calcium carbonate) which was on par with the S_2B_3. Lowest Zn uptake (77.21 µg pot^{-1}) was observed under interaction of 0.00 mg B kg^{-1} of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1. Similar results were reported by Waghadhare *et al.* (2007).

4.2.3.6 Effect of levels of B on iron uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The iron uptake by blackgram with varied levels of boron application in calcareous soils are presented in the table 4.26 and depicted graphically in figure 4.40.

Irrespective of the graded levels of boron, uptake of Fe by blackgram decreased significantly with increased calcium carbonate content of the soils from S_1 to S_5. Maximum Fe uptake (2680.35 µg pot^{-1}) in blackgram was observed in S_1 soil while minimum (879.72µg pot^{-1}) was observed in S_5 soil. The primary factor associated with reduced Fe under calcareous conditions appeared to be the effect of the bicarbonate ion (HCO_3) on Fe uptake and/or translocation in the plant. The result was Fe inactivation or immobilization in plant tissue. In calcareous soils, the solubility of iron was low due to the high carbonate content which in turn reduced the availability and uptake of iron by plants in calcareous soils (Singh and Joshi, 2000).

Iron uptake by blackgram increased progressively at varied levels of boron, irrespective of calcium carbonate content of soils and the difference recorded over control (B_0) was significant. Maximum Fe uptake (2068.23 µg pot^{-1}) was observed at B_3 level while minimum Fe uptake (1454.00 µg pot^{-1}) was observed at B_0 level. At varied levels of boron percent increase over control was 19.13, 35.54 and 42.24 at B_1, B_2 and B_3 levels, respectively. Alveraz-Tinaut, (1990) found a positive relation between B and Fe. Similar results were reported by Waghadhare *et al*. (2007).

Interaction effect between applied boron and soils was significant except at S_5 level. Highest Fe uptake (3043.65 µg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} of soil for S_1 level (1.08% calcium carbonate). Lowest Fe uptake (765.94 µg pot^{-1}) was observed under interaction of 0.00 mg B kg^{-1} of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1 and S_5B_2. These results were in accordance with the Niaz *et al*. (2011).

4.2.3.7 Effect of levels of B on manganese uptake of blackgram grown in calcareous soils of collected from Sattenapalli mandal, Guntur district

The data regarding the effect of levels of boron on manganese uptake of blackgram grown in calcareous soils are presented in the table 4.27 and depicted graphically in figure 4.41.

Soils (S_1 to S_5) with varied levels of calcium carbonate content (1.08, 5.25, 10.37, 16.20 and 17.75% $CaCO_3$) had significant influence on manganese uptake by blackgram. Irrespective of the graded levels of boron, uptake of Mn by blackgram decreased significantly with increase in calcium carbonate content of the soils from S_1 to S_5. Maximum Mn uptake (1279.92 µg pot^{-1}) in blackgram was observed in S_1 level while minimum (308.67µg pot^{-1}) was observed in S_5 level. Being the product of drymatter and nutrient content, uptake also follow the similar trend (Ganie *et al.*, 2014).

Manganese uptake by blackgram increased progressively at varied levels of boron, irrespective of calcium carbonate content of soils and the difference recorded over control (B_0) was significant. Maximum Mn uptake (963.06 µg pot^{-1}) was observed at B_3 level while minimum Mn uptake (599.65 µg pot^{-1}) was observed at B_0 level. At varied levels of boron percent increase over control was 25.63, 46.07 and 60.60. Similar results were reported by Patel and Golakiya (1986) in groundnut.

Interaction effect between applied boron and soils was significant except at S_5 level with B interaction. Highest Mn uptake (1468.44 µg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} of soil for S_1 level (1.08% calcium carbonate). Lowest Mn uptake (258.73 µg pot^{-1}) was observed under interaction of 0.00 mg B kg^{-1} of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1. Similar results were reported by Zada and Afzal, (1997).

4.2.3.8 Effect of levels of B on copper uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

The copper uptake by blackgram with varied levels of boron application in calcareous soils are presented in the table 4.28 and depicted graphically in figure 4.42

Irrespective of the graded levels of boron, uptake of Cu by blackgram decreased significantly with increase in calcium carbonate content of the soils from S_1 to S_5. Maximum Cu uptake (76.94 µg pot^{-1}) in blackgram was observed in S_1 soil while minimum (25.31µg pot^{-1}) was observed in S_5 soil. At varied levels of calcium carbonate content of soils, per cent decrease over S_1 was 5.13, 43.08, 55.28 and 67.10 at S_2, S_3, S_4 and S_5, respectively. Significant negative relationship was found between the $CaCO_3$ and Cu content where the available Cu decreased with increase in $CaCO_3$ content of soil (Vijaykumar *et al.*, 1996).

Copper uptake by blackgram increased progressively at varied levels of boron, irrespective of calcium carbonate content of soils and the difference recorded over control (B_0) was significant. Maximum Cu uptake (58.66 µg pot^{-1}) was observed at B_3 level while minimum Cu uptake (38.22 µg pot^{-1}) was observed at B_0 level. At varied levels of boron percent increase over control was 30.53, 46.49 and 53.47 at B_1, B_2 and B_3, respectively. These results were in accordance with Waghadhare *et al.* (2007) in tomato crop grown in calcareous Inceptisols.

Interaction effect between applied boron and soils was significant except at S_5 level with B interaction. Highest Cu uptake (89.65 µg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 level (1.08% calcium carbonate) which was on par with S_2B_3. Lowest Cu uptake (21.73 µg pot^{-1}) was observed under interaction of 0.00 mg B kg^{-1} (B_0) of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1. These results were in accordance with the Niaz *et al.* (2011) in greengram grown in calcareous soils of Punjab.

4.2.3.9 Effect of levels of B on boron uptake of blackgram grown in calcareous soils collected from Sattenapalli mandal, Guntur district

Results pertaining to the effect of levels of boron on boron uptake of blackgram grown in calcareous soils are presented in the table 4.29 and depicted graphically in figure 4.43.

Irrespective of the graded levels of boron, uptake of B by blackgram decreased significantly with increase in calcium carbonate content of the soils from S_1 to S_5. Maximum B uptake (90.07 µg pot^{-1}) in blackgram was observed in S_1 soil which contained 1.08% $CaCO_3$ while minimum (23.84µg pot^{-1}) was observed in S_5 soil (containing 17.75% $CaCO_3$). The decrease in B uptake with increase calcium carbonate content of soil might be due to decreased availability of B in soil (Shaaban *et al*., 2006).

Boron uptake by blackgram increased with increase in levels of applied boron from B_0 to B_3, irrespective of calcium carbonate content of soils and this increase over control (B_0) was significant. Maximum B uptake (67.14 µg pot^{-1}) was observed at B_3 level while minimum B uptake (38.73 µg pot^{-1}) was observed at B_0 level. At varied levels of boron percent increase over control was 25.17, 59.90 and 73.35, at B_1, B_2 and B_3, respectively. The experimental soils were low in available B (< 0.5 ppm) except S_1 and this might be one of the reasons for response to B levels. The increase in B uptake might be due to increased availability of the nutrient. Similar favourable effect B on B uptake was reported by Shamsuddoha *et al*. (2011) in wheat crop.

Combined effect of boron application and soils showed increased B uptake significantly except at S_5 soil. Highest B uptake (110.81 µg pot^{-1}) by blackgram was recorded under the interaction of 0.50 mg B kg^{-1} (B_2) of soil for S_1 soil (1.08% calcium carbonate) which was on par with S_1B_3 and S_2B_3. Lowest B uptake (20.28 µg pot^{-1}) was observed under interaction of 0.00 mg B kg^{-1} (B_0) of soil for S_5 level (17.75% calcium carbonate) which was on par with S_5B_1. These results were in accordance with the Waghadhare *et al*. (2007) in tomato crop grown in calcareous inceptisols.

Chapter V

SUMMARY AND CONCLUSIONS

The present investigation entitled “Boron availability and response of blackgram to boron in calcareous soils” was conducted at Agricultural College, Bapatla in the Department of Soil Science and Agricultural Chemistry.

Representative surface soil samples (50) were collected from different villages of Sattenapalli mandal in Guntur district by following random sampling technique. The soil samples were processed and analysed for their physical properties (mechanical composition, BD, WHC), physico-chemical properties (pH, EC, organic carbon, calcium carbonate, CEC, exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and PBS), available macronutrients (nitrogen, phosphorus and potassium) and micronutrients (zinc, iron, manganese, copper and boron). Correlations were worked out among different soil properties.

Critical examination of the data revealed that soils of the study area in general were dominantly fine textured clay followed by sandy clay. Clay content of the soils was significantly and positively correlated with $CaCO_3$ content (0.286*) and exchangeable Ca^{2+} (0.559**). The soil reaction was moderately alkaline and it ranged from 7.21-8.52. Negative correlation was observed between pH and soil available B (r=-318*). The soils were non-saline (on an average 0.92dS m^{-1}) with EC varying from 0.04-3.12 dS m^{-1}. Physical properties *viz*., bulk density and WHC of soils ranged from 1.23 to 1.55Mg m^{-3} and 45.23 to 58.89 percent, respectively. The organic carbon content was low and it ranged from 0.15-0.75with a mean of 0.42 per cent. It showed a negative correlation with $CaCO_3$ content (r=-0.372*).

The soils of Sattenapalli mandal were slight to strongly calcareous and varied in between 1.08 and 17.75 per cent$CaCO_3$. Based on the $CaCO_3$ content of soils 60, 32and 6 per cent of the samples were slightly, moderately and strongly calcareous, respectively.

Cation exchange capacity of soils was in between32.61 and 52.17 cmol (p+) kg^{-1}, conspicuously, it was found to be significantly and positively correlated with clay (0.529**) content. Base saturation of the soils was high and varied from 86.66 to 98.73 per cent. The exchangeable bases on the complex followed a trend of Ca^{2+} > Mg^{2+}> Na^{+}> K^{+} indicating the calcareousness of the soils.

The investigation revealed that in general the soils of Sattenapalli mandal were low in organic carbon as well as nitrogen, medium in phosphorus and high in potassium. Available nitrogen of the soils ranged from 142.1 to 292.6 kg ha^{-1}. The nutrient index values indicated that the soils were low in available nitrogen and phosphorus and high in potassium status. Among the analysed samples, 92 per cent were low in available N. As expected, available N showed a significant positive correlation with organic carbon. However, a negative correlation was observed with $CaCO_3$ (r=-327*). Available P content of soils varied from 11.0-75.2kg ha^{-1}.Data revealed that 44 per cent of the samples were low in P_2O_5 and 80 per cent high in K_2O. Available P_2O_5 was negatively correlated with $CaCO_3$(r=-340*). Available K_2O content of the soil was in between 152.6 and 709.4 kg ha^{-1}. It is noteworthy that available K content of the soils showed a positive correlation with $CaCO_3$ (r=302*).

Soils in the mandal were deficient in boron (64%). Calcareousness of the soils was significant negatively correlated with soil available boron (r=-592*). With respect to micronutrient status, majority of soils were sufficiently rich in iron (90%) and manganese. Micronutrients *viz.*, Fe, Zn and Cu showed a negative trend with $CaCO_3$ content.

A pot culture experiment was conducted in the green house of Department of Soil Science and Agricultural Chemistry, Agricultural College, Bapatla during 2015 to find out the response of blackgram with different levels of boron application in calcareous soils of the study area. The experiment was laid out in a completely randomized design with two factors (Figure 3.3). The first factor was the soil (5) containing different levels $CaCO_3$ (1.08, 5.25, 10.37, 16.20 and 17.75) and the second factor was the levels of boron consisting of four levels 0.00, 0.25, 0.50 and 0.75 mg boron kg^{-1} of soil. Boron was given in the form of boric acid (H_3BO_3) as per the treatments. Altogether there were twenty treatments was replicated thrice. Biomass production and seed yield at harvest were recorded. Content and uptake values were computed for nutrients viz., N, P, K, S, Zn, Fe, Mn, Cu and B. The salient findings of the experiment are summarized.

It was found that, with increased levels of boron application, biomass production, seed yield, and nutrient content and nutrient uptake by blackgram were enhanced irrespective of $CaCO_3$ level of the soils.

The highest biomass production and seed yield were observed in S_1 soil which contained 1.08% $CaCO_3$ with the application of 0.50 mg B kg^{-1} (B_2) of soil while the lowest values was observed in S_5 (containing 17.75% $CaCO_3$) soil with the application of 0 mg B kg^{-1} of soil (control). Highest content and uptake of macro and micronutrients (N, P, K, S, Zn, Fe and Cu) were recorded in soil with 1.08% $CaCO_3$which received of 0.50 mg B kg^{-1} (S_1B_2) while the lowest values was observed in S_5B_0 (i.e., 17.75% $CaCO_3$ with no application of boron).However soil with the application of 0.75 mg B kg^{-1}in soil with 1.08% $CaCO_3$(S_1B_3) recorded the highest B and Mn content whereas, lowest B and Mn contents were observed in S_5B_0 where the soil contained 17.75% $CaCO_3$and received no boron(control).

Thus, under the conditions of present investigation, for soils containing 1.08% $CaCO_3$ application of B @ 0.25 mg kg^{-1} soil (B_1) was found sufficient to produce optimum yield of blackgram though the maximum yield obtained with application of B @ 0.50 mg kg^{-1} soil (B_2) was on par with B_1 level.

For all other soils having more than 1.08% $CaCO_3$ content, the yields were increased with increase in B doses under study. The B dose needed to obtain optimum yields must be studied further.

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Note: The literature is cited as per the “Thesis Guidelines” prescribed by Acharya N. G. Ranga Agricultural University, Guntur.

APPENDIX A

Particulars of the soil samples collected in Sattenapalli mandal of Guntur district, A.P.

S.No	Village name	GPS coordinates	
1	Nandigama	N-16^{0}40.854`	E-80^{0}21.761`
2	Nandigama	N-16^{0}40.957`	E-80^{0}21.933
3	Nandigama	N-16^{0}41.283`	E-80^{0}21.074`
4	Nandigama	N-16^{0}39.910`	E-80^{0}18.654`
5	Nandigama	N-16^{0}40.339`	E-80^{0}18.705`
6	Pedamakkena	N-16^{0}44.880`	E-80^{0}24.349`
7	Pedamakkena	N-16^{0}44.074`	E-80^{0}24.040`
8	Pedamakkena	N-16^{0}45.189`	E-80^{0}24.367`
9	Pedamakkena	N-16^{0}45.395`	E-80^{0}23.749`
10	Pedamakkena	N-16^{0}43.816`	E-80^{0}23.989`
11	Gudipudi	N-16^{0}43.171`	E-80^{0}20.728`
12	Gudipudi	N-16^{0}44.253`	E-80^{0}20.765`
13	Gudipudi	N-16^{0}42.296`	E-80^{0}21.606`
14	Gudipudi	N-16^{0}42.536`	E-80^{0}20.765`
15	Gudipudi	N-16^{0}41.558`	E-80^{0}22.139`
16	Kantepudi	N-16^{0}39.738`	E-80^{0}21.812`
17	Kantepudi	N-16^{0}39.652`	E-80^{0}21.606`
18	Kantepudi	N-16^{0}38.536`	E-80^{0}22.276`
19	Kantepudi	N-16^{0}38.502`	E-80^{0}21.950`
20	Kantepudi	N-16^{0}38.742`	E-80^{0}21.452`
21	Bhatluru	N-16^{0}47.763`	E-80^{0}07.453`
22	Bhatluru	N-16^{0}48.449`	E-80^{0}07.933`
23	Bhatluru	N-16^{0}46.784`	E-80^{0}07.642`
24	Bhatluru	N-16^{0}45.926`	E-80^{0}10.955`
25	Bhatluru	N-16^{0}46.096`	E-80^{0}10.813`
26	Bhrugubanda	N-16^{0}49.737`	E-80^{0}19.435`
27	Bhrugubanda	N-16^{0}50.904`	E-80^{0}19.418`
28	Bhrugubanda	N-16^{0}50.286`	E-80^{0}20.036`
29	Abburu	N-16^{0}45.136`	E-80^{0}16.208`
30	Abburu	N-16^{0}45.909`	E-80^{0}16.150`
31	Abburu	N-16^{0}46.355`	E-80^{0}16.465`
32	Abburu	N-16^{0}45.789`	E-80^{0}15.521`
33	Pakalapadu	N-16^{0}45.892`	E-80^{0}14.783`
34	Pakalapadu	N-16^{0}45.737`	E-80^{0}14.045`
35	Pakalapadu	N-16^{0}46.612`	E-80^{0}14.027`
36	Pakalapadu	N-16^{0}47.351`	E-80^{0}14.062`
37	Pakalapadu	N-16^{0}45.256`	E-80^{0}14.165`
38	Pakalapadu	N-16^{0}45.548`	E-80^{0}13.684`
39	Pakalapadu	N-16^{0}45.480`	E-80^{0}13.118`

Contd...

40	Kattamuru	N-16^{0}48.810`	E-80^{0}15.229`
41	Kattamuru	N-16^{0}47.591`	E-80^{0}14.817`
42	Kattamuru	N-16^{0}46.887`	E-80^{0}14.886`
43	Gandluru	N-16^{0}45.276`	E-80^{0}14.904`
44	Gandluru	N-16^{0}44.881`	E-80^{0}14.629`
45	Gandluru	N-16^{0}45.224`	E-80^{0}14.749`
46	Komerapudi	N-16^{0}37.722`	E-80^{0}20.412`
47	Komerapudi	N-16^{0}37.636`	E-80^{0}19.794`
48	Komerapudi	N-16^{0}37.962`	E-80^{0}21.168`
49	Komerapudi	N-16^{0}37.722`	E-80^{0}21.597`
50	Komerapudi	N-16^{0}37.465`	E-80^{0}20.172`

APPENDIX- B

Village wise particulars of the soil samples collected in Sattenapalli mandal of Guntur district, A.P.

S.No.	Village name	No of soil samples
1	Nandigama	5
2	Pedamakkena	5
3	Gudipudi	5
4	Kantepudi	5
5	Bhatluru	5
6	Bhrugubanda	3
7	Abburu	4
8	Pakalapadu	7
9	Kattamuru	3
10	Gandluru	3
11	Komerapudi	5

APPENDIX - C

Soil properties	**S_1 (1.08%)**	**S_2 (5.25%)**	**S_3 (10.37%)**	**S_4 (16.20%)**	**S_5 (17.75%)**
OC (%)	0.71	0.69	0.51	0.34	0.21
pH	8.06	8.17	8.43	8.45	8.52
CaCO3 (%)	1.08	5.25	10.37	16.20	17.75
Ex Ca^{2+}	34.85	28.49	34.55	38.15	37.85
N (kg ha^{-1})	288.16	261.12	200.98	192.12	181.89
P_2O_5 (kg ha^{-1})	75.24	36.00	25.97	22.81	12.23
K_2O (kg ha^{-1})	455.44	411.64	499.23	709.43	534.26
S (ppm)	16.67	16.21	16.01	8.23	8.12
Fe (ppm)	22.95	12.57	4.48	4.21	4.11
Mn (ppm)	8.31	5.81	3.01	2.42	1.98
Zn (ppm)	0.62	0.56	0.42	0.35	0.29
Cu (ppm)	1.56	1.52	1.47	0.20	0.18
B (ppm)	0.64	0.41	0.22	0.20	0.12

Properties of selected five calcareous soil samples in the study area (Sattenapalli mandal, Guntur district)